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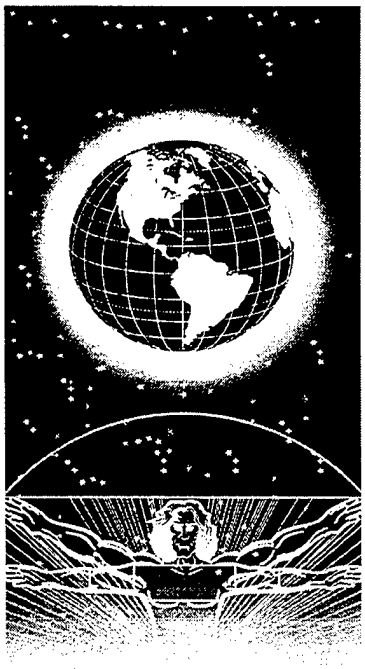

UNITED STATES AIR FORCE RESEARCH LABORATORY

MAXPAC Test Program Final Presentation

Joseph Morris

Aerojet
Propulsion Division
P.O. Box 13222
Sacramento CA 95813-6000

December 1996

Final Report for the Period July 1996 to December 1996

Human Effectiveness Directorate
Biodynamics and Protection Divison
Biodynamics and Acceleration Branch
2800 Q Street BLDG 824 RM 206
Wright-Patterson AFB OH 45433-7947

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TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-SR-2001- **0006**

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

F. WESLEY BAUMGARDNER
Acting Chief, Biodynamics and Protection Division
Human Effectiveness Directorate
Air Force Research Laboratory

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Veridian Engineering, Inc.
Human Effectiveness Group
5200 Springfield St., Suite 200
Dayton OH 45431-1285

Aerojet
Propulsion Division
P.O. Box 13222
Sacramento CA 95813-6000

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This report summarizes the results of a United States Air Force funded effort to demonstrate the Multi-Axis Pintle Attitude Control (MAXPAC) system. The MAXPAC system is a spin-off of the Fourth Generation Escape Systems Technology Demonstration Program. MAXPAC uses four discrete, pintle-controlled rocket nozzles to provide variable thrust in three axes. The intent is to provide an under-seat retrofit for the Advanced Concept Ejection Seat (ACES) II replacing the current pitch stabilization rocket with the three-axis stabilization MAXPAC.

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Escape system, pintle-control, stabilization

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57

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PREFACE

This report was prepared under contract F41624-95-C-6014, Task 62, Engineering Support of Biodynamics Research – Crew Escape Technologies (CREST) Demonstration Support. The Prime Contractor for this effort was Veridian Engineering, Inc., Dayton, OH and the major subcontractor was Aerojet – Propulsion Division of Sacramento CA.

This Final Report summarizes the results of a United States Air Force funded effort during the period July through December 1996 to demonstrate the Multi-Axis Pintle Attitude Control (MAXPAC) system. The MAXPAC system is a spin-off of the Fourth Generation Escape System Technology Demonstration program. The intent of the program was to provide an under-seat retrofit for the Advanced Concept Ejection Seat (ACES) II replacing the current pitch stabilization rocket with the three-axis stabilization MAXPAC.

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  - REVIEW OF TEST ARTICLE DESIGN
  - KISTLER LOAD TABLE DESCRIPTION
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  - TEST DATA REVIEW AND GROUND TEST GROUNDING ISSUES
  - CONCLUSIONS & RECOMMENDATIONS

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MAXPAC OVERVIEW

JOE MORRIS

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MAXPAC MOTOR TEST PROGRAM OBJECTIVES

OBJECTIVE	STATUS
DESIGN & ANALYSIS	CMPLT
MOTOR ASSEMBLY AND BENCH TESTING	CMPLT
TEST PLANS	CMPLT
GROUND STATIC MOTOR TESTS	CMPLT
REPORTING: MONTHLY TECHNICAL & BUDGET, MOTOR TEST QUICKLOOK	CMPLT
MEETINGS: KICK-OFF, TRR, AND FINAL PRESENTATION	66% CMPT

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MAXPAC TEST ARTICLE DESIGN REVIEW

BILL BARNETTE

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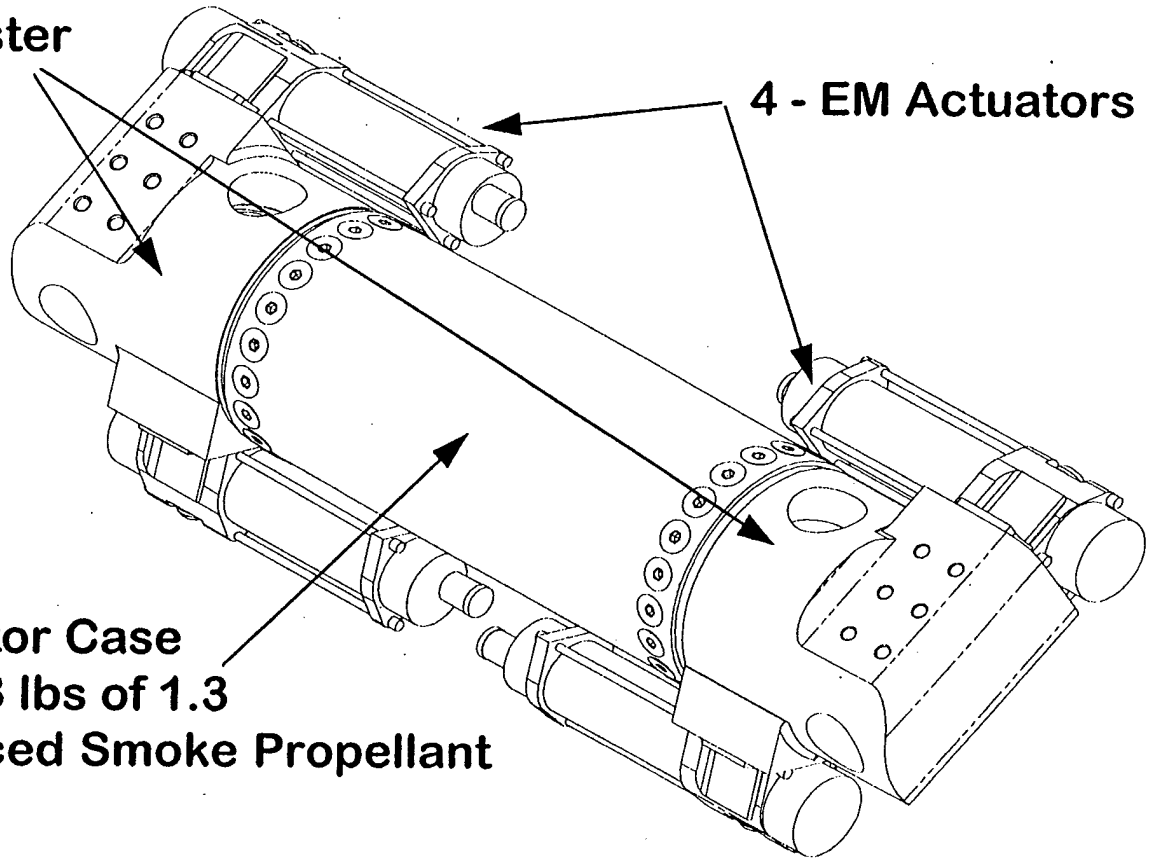
HEAVYWEIGHT MOTOR CONFIGURATION



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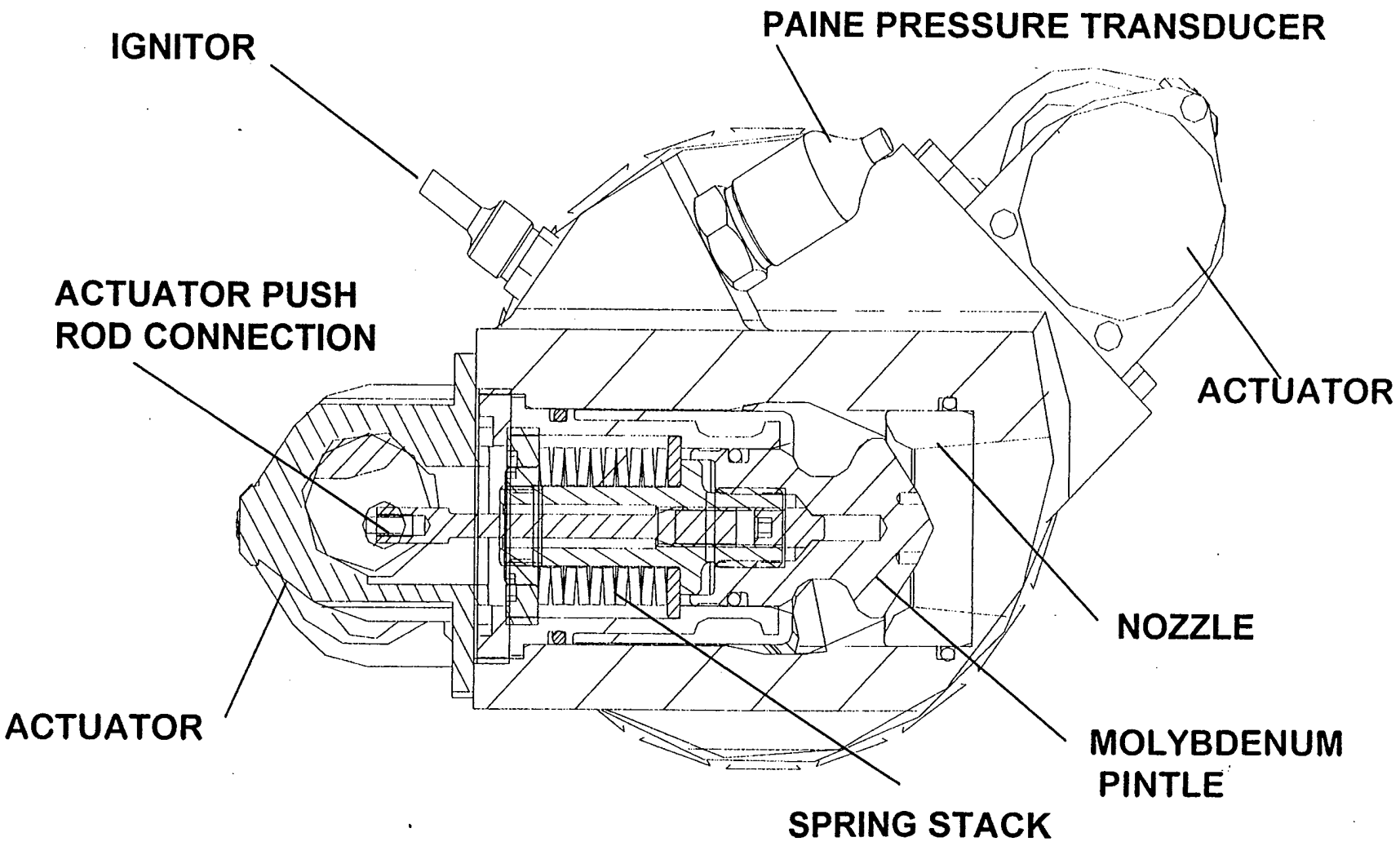
MAXPAC PINTLE MODULE ASSEMBLY



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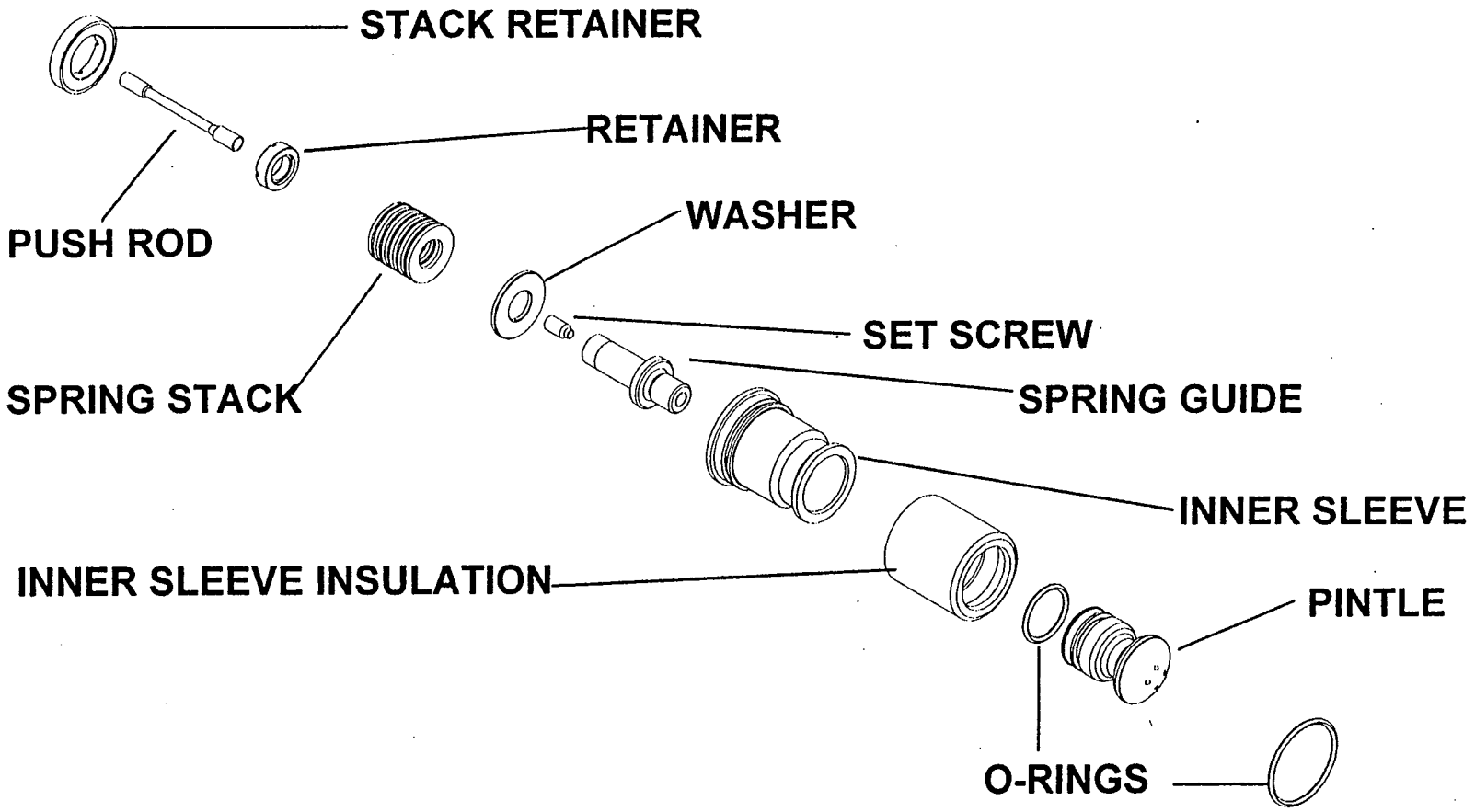
MAXPAC PINTLE MODULE



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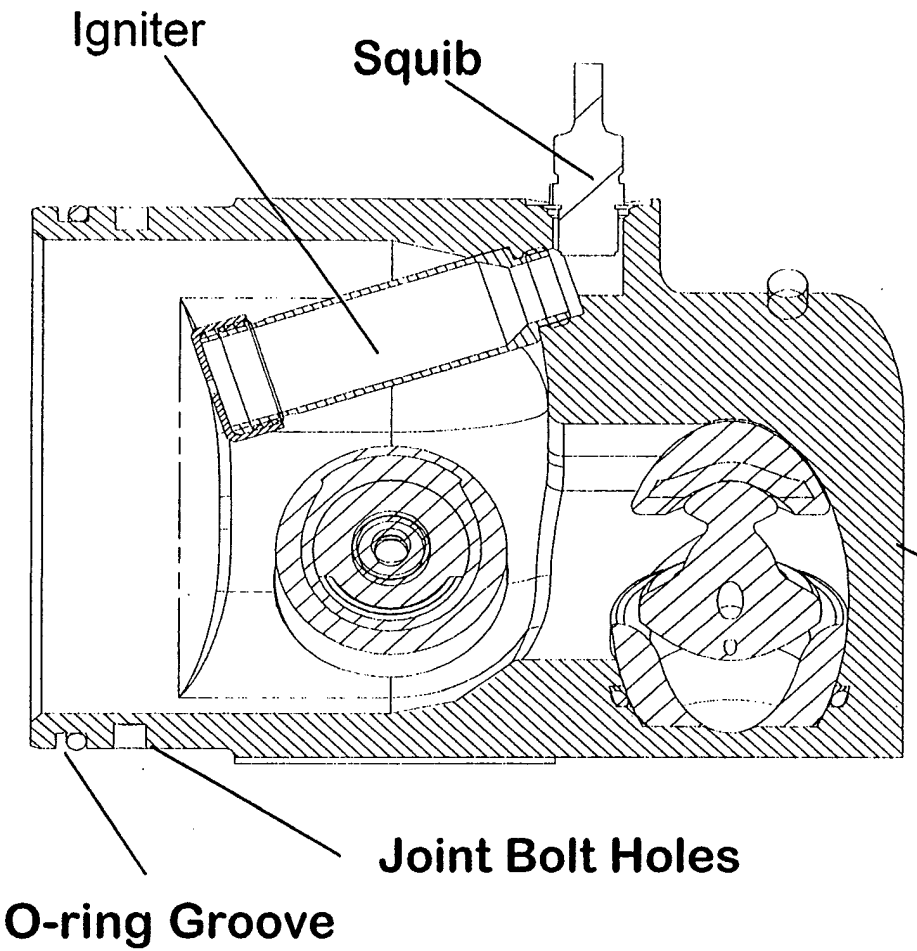
MAXPAC IGNITER



- 64 BKN03-2A Pellets (10 grams)
- Quantic , dual bridgewire squib
- Located in Thruster Housing 1-2

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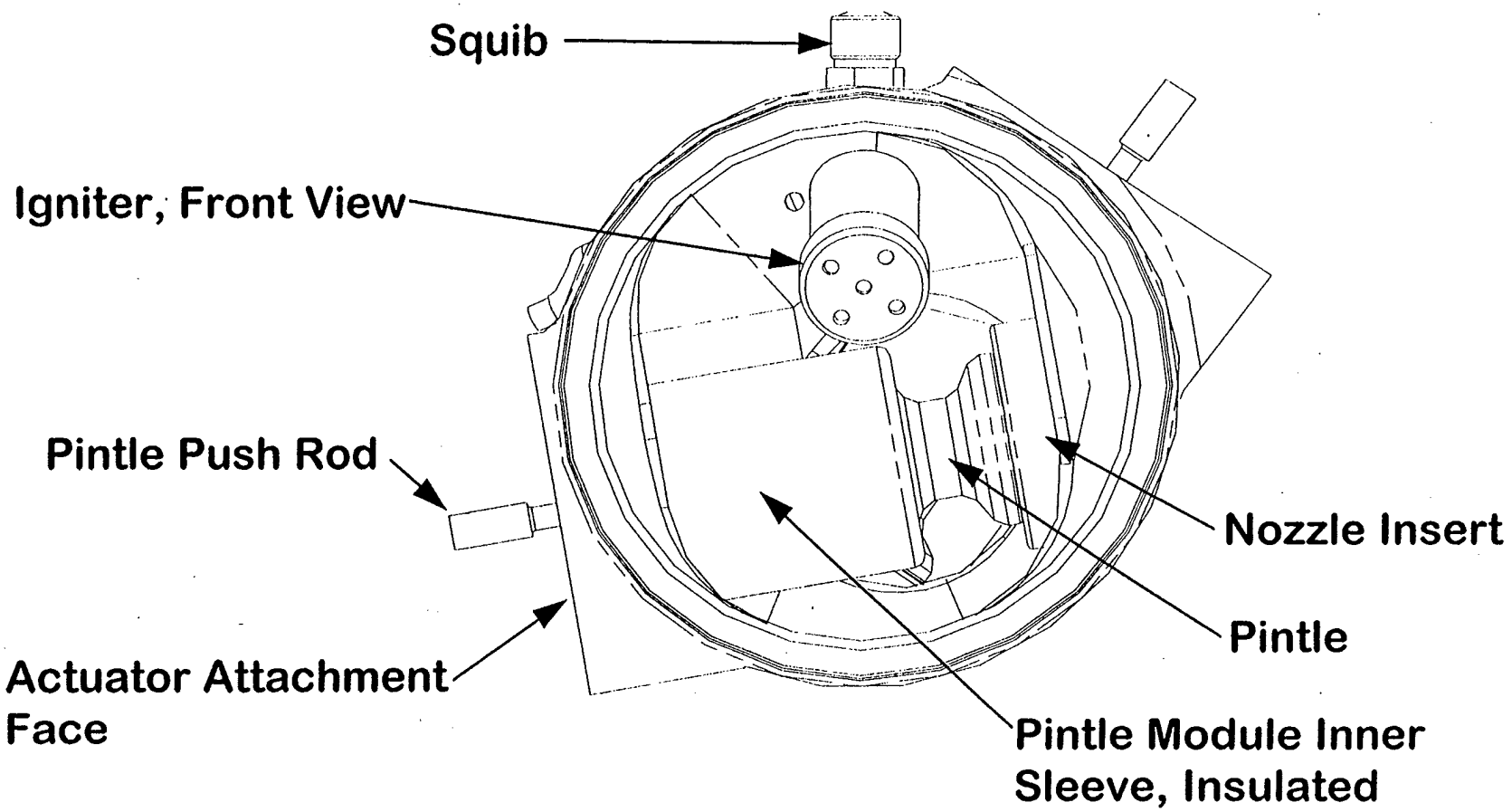
THRUSTER HOUSING, INSIDE VIEW



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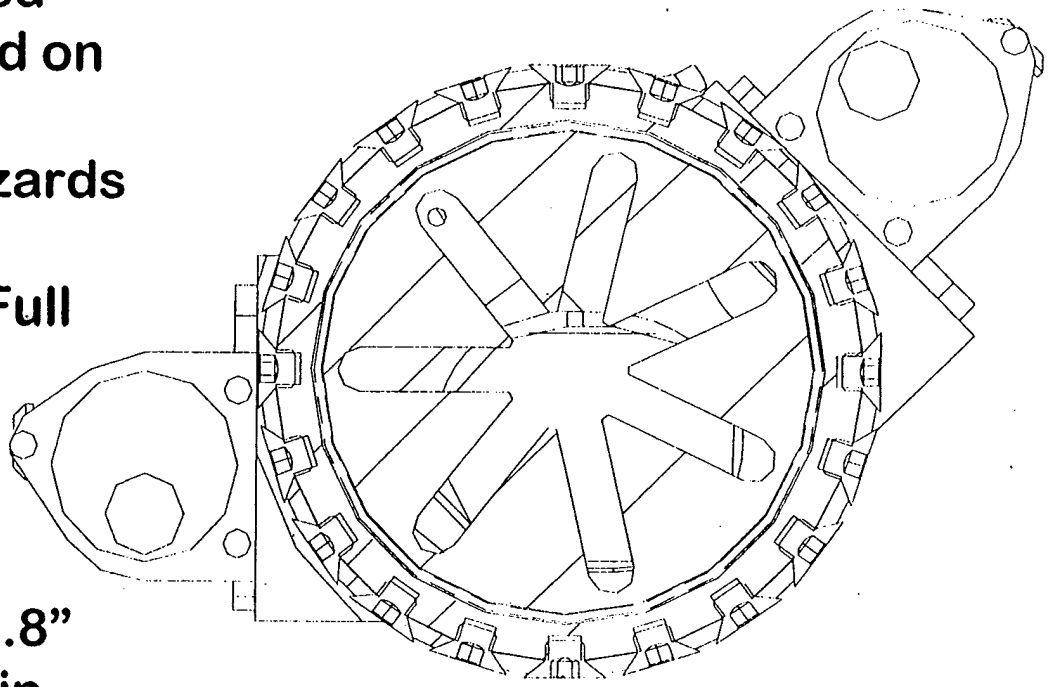
MAXPAC PROPELLANT

- 4.3 Pounds of Modified ANB-3679, Developed on the ARS Program
- Reduced Smoke, Hazards Class 1.3
- 7- Fin Grain Design, Full Length
- Elastomer Liner for Propellant to Case Bonding
- ~9.0 inches Long, ~ 3.8" OD, ~0.8" ID, ~ 0.3" Fin Gap



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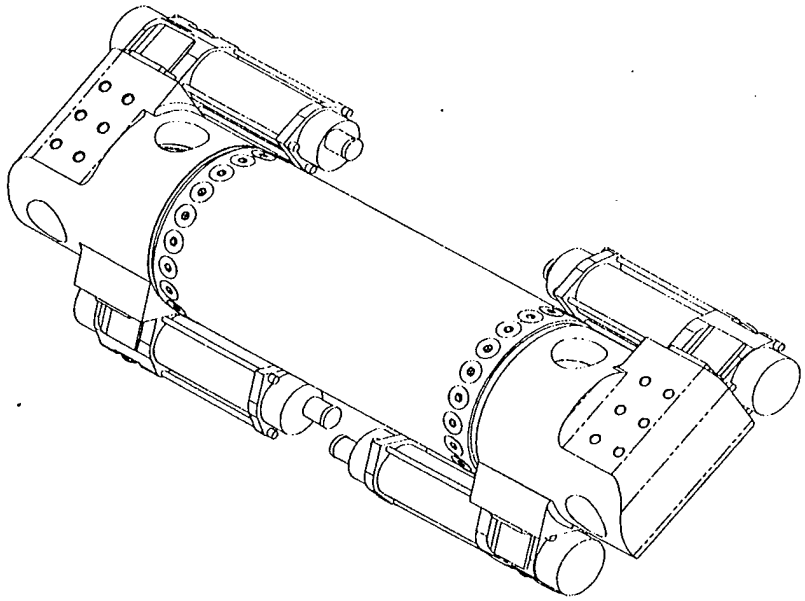
MAJOR COMPONENTS

ARMAMENTS DEFENSE TACTICAL

- 4- Electro-Mechanical Actuators
  - 150 VDC, 40 Amp
  - Stall Load >300 Lbf
  - Stroke > 0.22", > 120 Hz
- 1- Quad Actuator Controller
- 2- 5K Flightweight Paine Pressure Transducers, PN 177398
- 2- 5K Taber Pressure Transducers, Facility Equipment
- Kistler Load Measuring Table
- Motor Hold Down Brackets



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CONTROLS

- Control Logic in "C"
- EDACS (Engineering Data Acquisition and Control)
  - » Pentium 90MHz
  - » National Instruments Data Acquisition Boards
  - » Ectron Strain Gage Amplifiers
  - » Validyne Amplifiers
  - » Ordnance Firing Circuit
- Sample Rate of 400 Samples / Second
- Backup Data on Separate PC486/50

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CONTROL LOGIC

- MAXPAC Control Logic Identical to 4TH GEN Initial Testing Logic
- Two Paine Amplified Pressure Transducers for Control
- Transducer Logic Checks for Bad Transducer
- Thrust Commands Limited to Available System Thrust
- Initial Pintle Positions at Spring 0-Load Point
- Versatron Actuators
  - » 120 Hz Bandwidth
  - » 15 Inches / Second
  - » 360 lbf
  - » 140 VDC @ 40 amps

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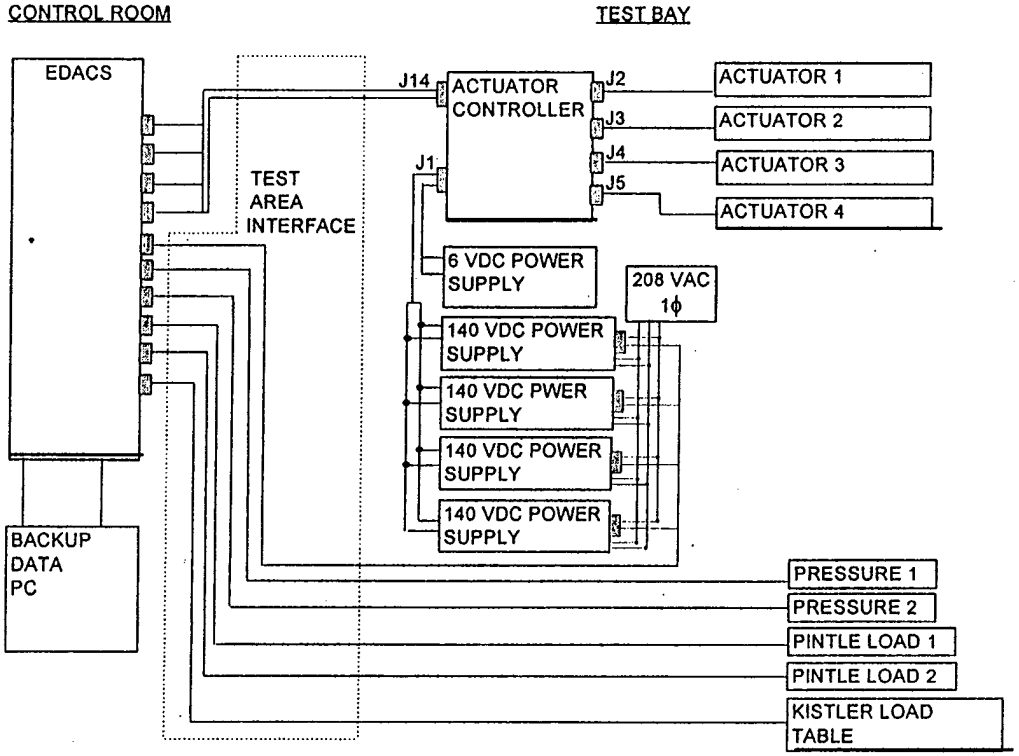
MAXPAC GROUND TESTING ELECTRICAL INTERFACE



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MAXPAC
INSTRUMENTATION LIST

Function	Name	Range	Notes
Chamber Pressure	PC - 1 & 2	0 - 5,000 psia	2Paines-2Tbrs
Igniter Circuit Current	II - 1	TBD amps	
Pintle Actuators (1-4) Current	IAP-1 thru IAP-4	0 -40 amps	
Pintle Actuators (1-4) Voltage	EAP-1 thru EAP-4	0 - 1400 volts	
Pintle #1 Actuator Command	CAP-1 thru CAP-4	0 - 10 volts	
Pintle Position	PP-1 thru PP-4	0 - 0.25 inch	
Forces along X, Y Axes	FX, FY	± 4496 lbf	Tests 2 & 3
Forces along Z Axis	FZ	-4496 to 8993 lbf	Tests 2 & 3
Moments about X, Y Axes	MX, MY	± 369 ft-lbs	Tests 2 & 3
Moments about Z Axis	MZ	± 738 ft-lbs	Tests 2 & 3

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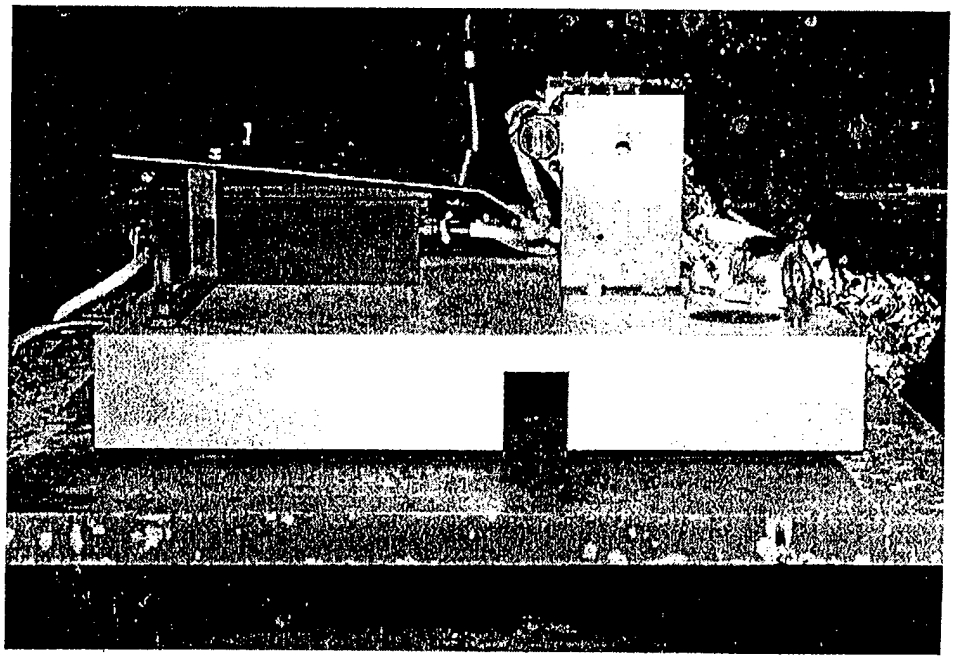
KISTLER LOAD

- Multi-component Force Plate Provides 3 Orthogonal Components Of Force, Fx, Fy, & Fz
- Fx&y = ± 4496 lbf; Fz=-4496 to 8993 lbf
- High Frequency due to Stiffness
- 4 - 3 axis Quartz Type Load Cells
- Micro-Processor/ Amplifier, Determines Moments and Resultant Forces



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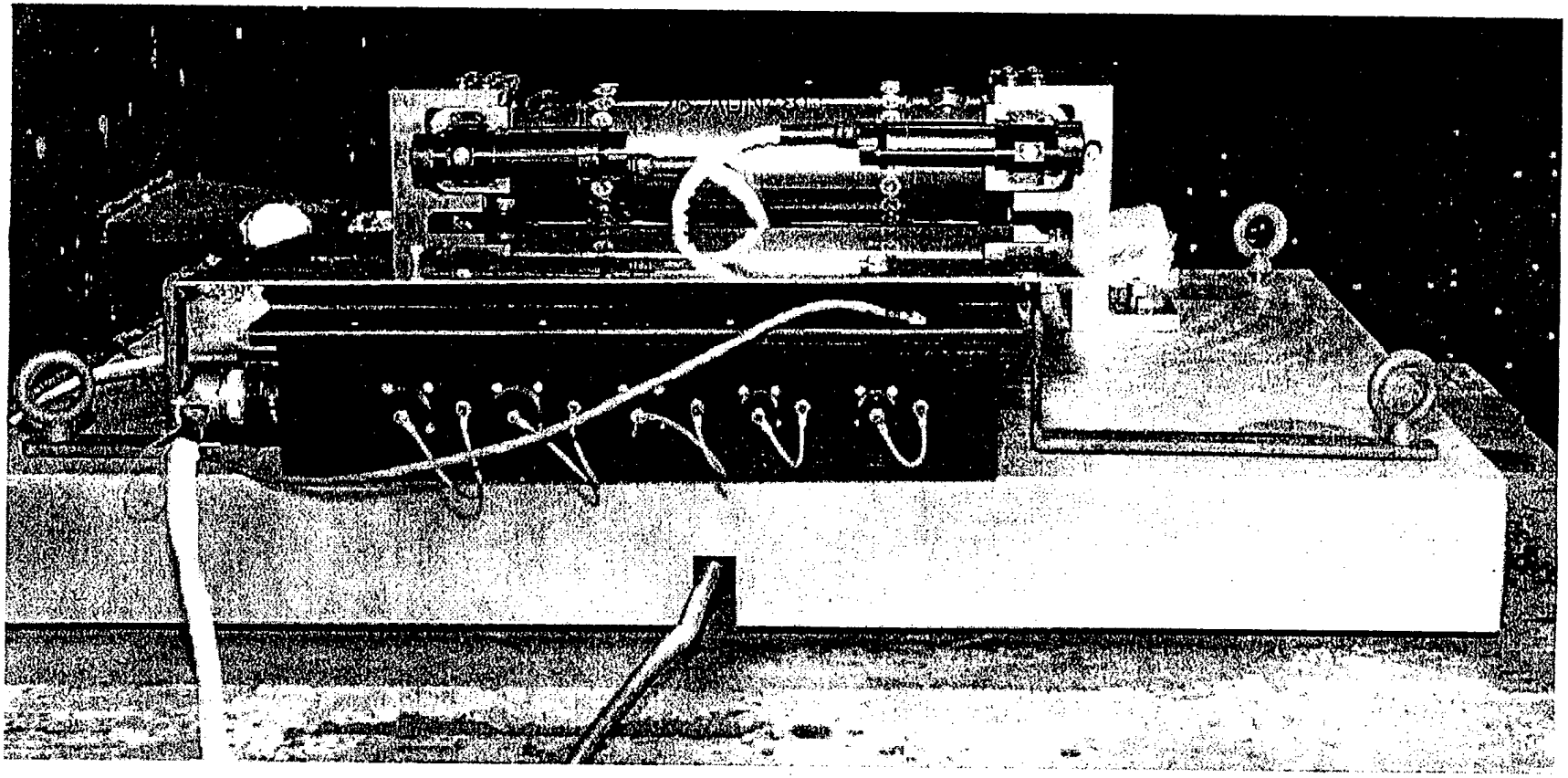
KISTLER LOAD TABLE
REAR VIEW



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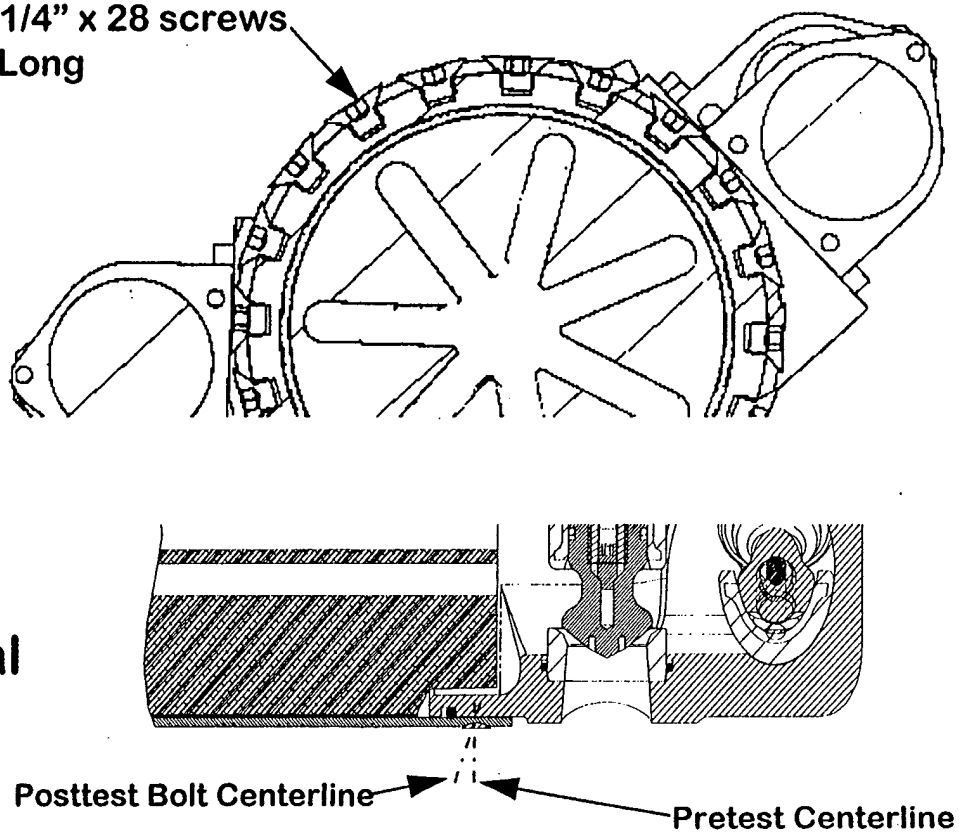
PROOF TEST CRITERIA & RESULTS

- Hydro-Proof Test
  - Motor Assembled as Planned with Nozzle Plugs
  - Max Pressure 4600 psi
- Motor Held Target Pressure for 60 Seconds
- Joint Failed- Bolts Pulled from Bolt Hole: Bolt L/D was to Small, < 0.7 Critical Ratio



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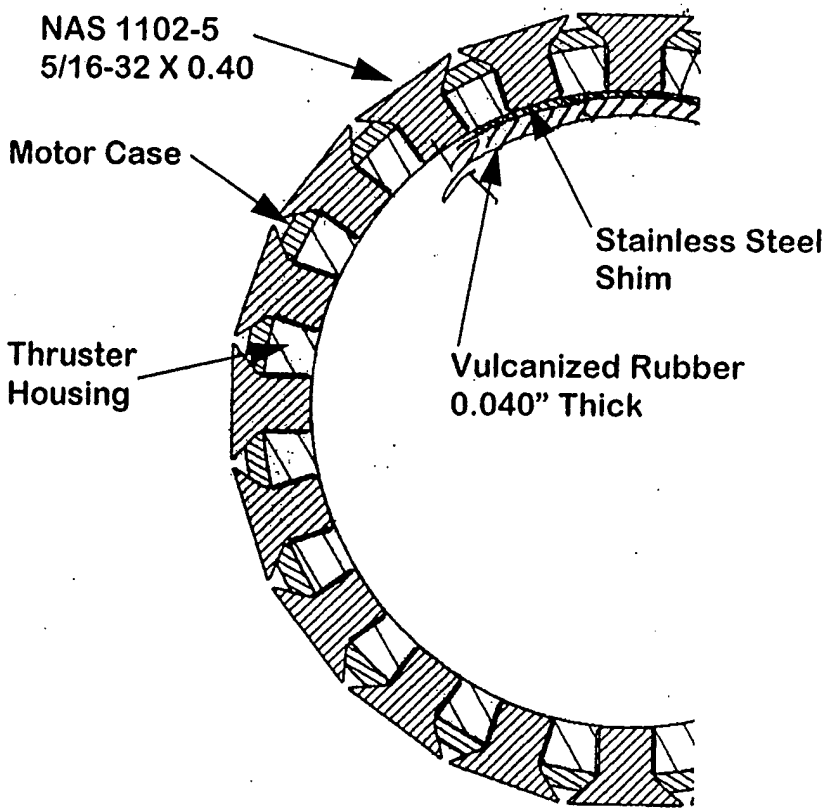
MOTOR CASE JOINT NEAR TERM FIX

- Brainstorming Session Lead to Near Term Fix
  - Salvage Existing Hardware
  - Must Use Larger Bolts
  - Drill Through Thruster Housing To Acquire More Length
  - Bond in Stainless Steel Shim
  - Coat Shim Joint with vulcanized rubber
  - Consequently Increased L/D
- Long Term Fix, Redesigned Joint, Probably Lockwire



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MAXPAC TEST DATA REVIEW AND GROUND TEST GROUNDING ISSUES

KEVIN PETERSON

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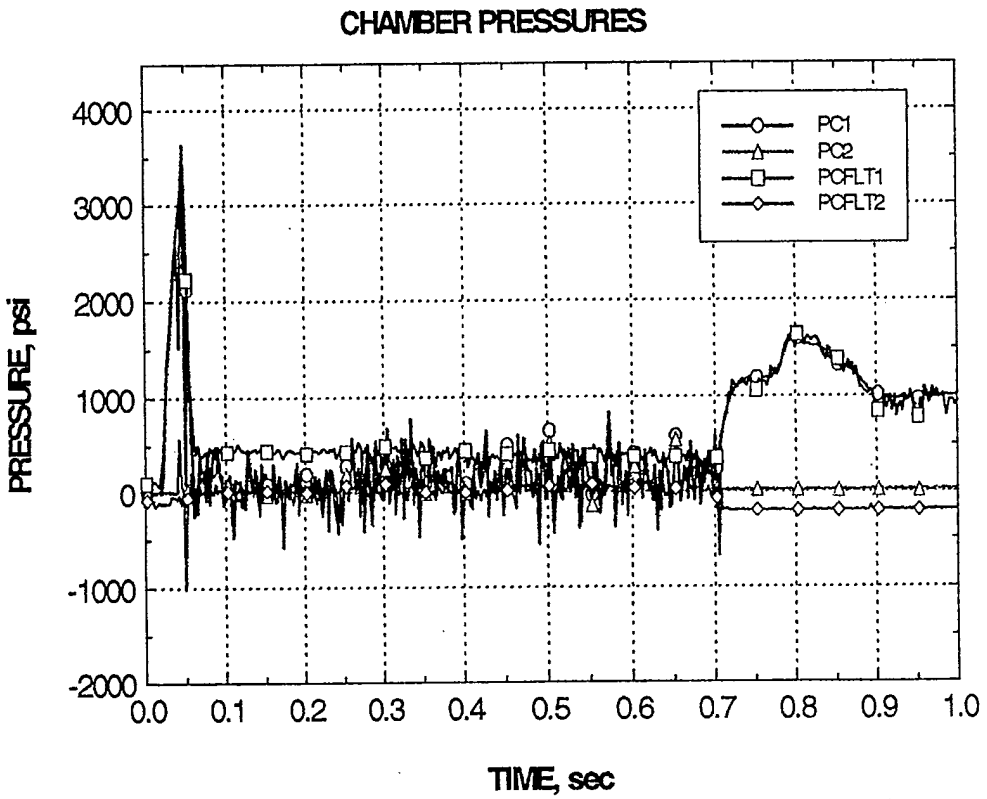
MAXPAC TEST 100 RESULTS

- Pressure Rise Normal on Number 1 Side
- Pressure Port Blocked on Number 2 Side
- Pressure Dropped Due to Abort
- Pressure Rise at End When Pintles Moved to No Load Point



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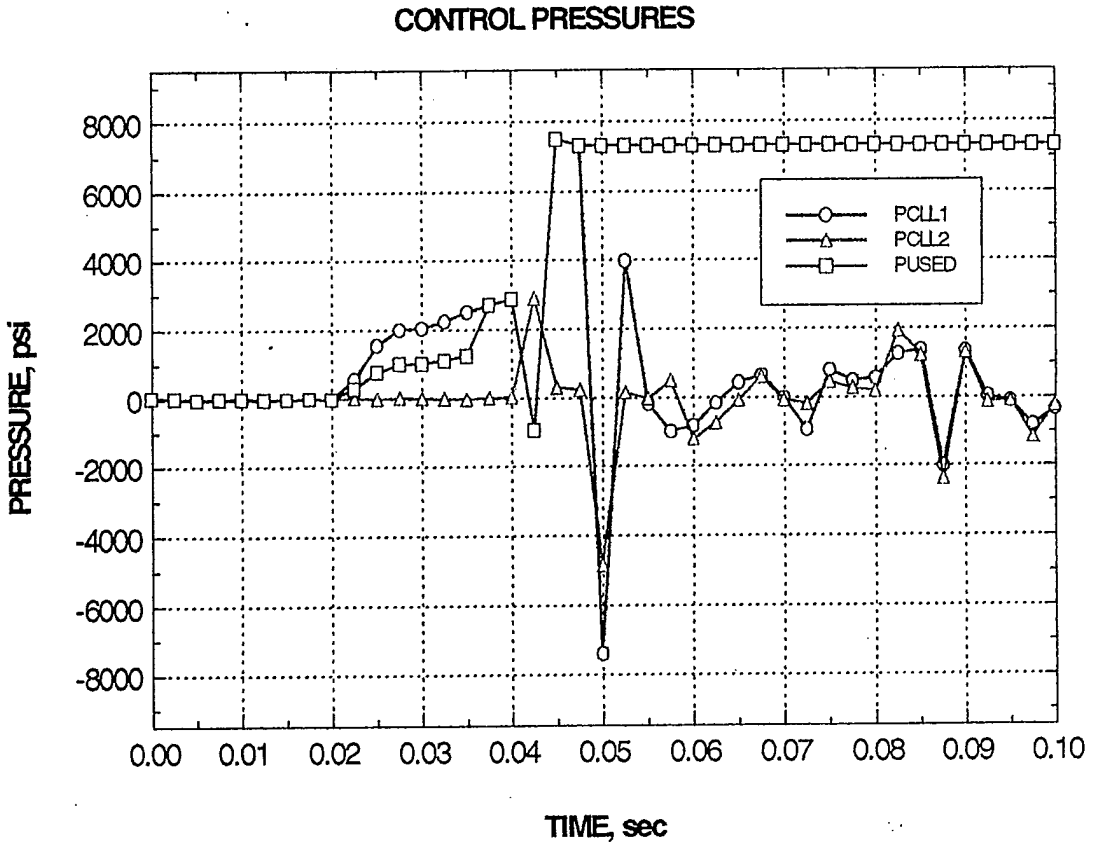
MAXPAC TEST 100 RESULTS

- Control Pressure 2 Thrown Out Due to Delta PC > 200 for 6 Continuous Samples
- Control Pressure 1 Thrown Out Due to 3 Continuous Samples of PC < -150 or PC > 5000
- Both Transducers Bad, Test Aborted



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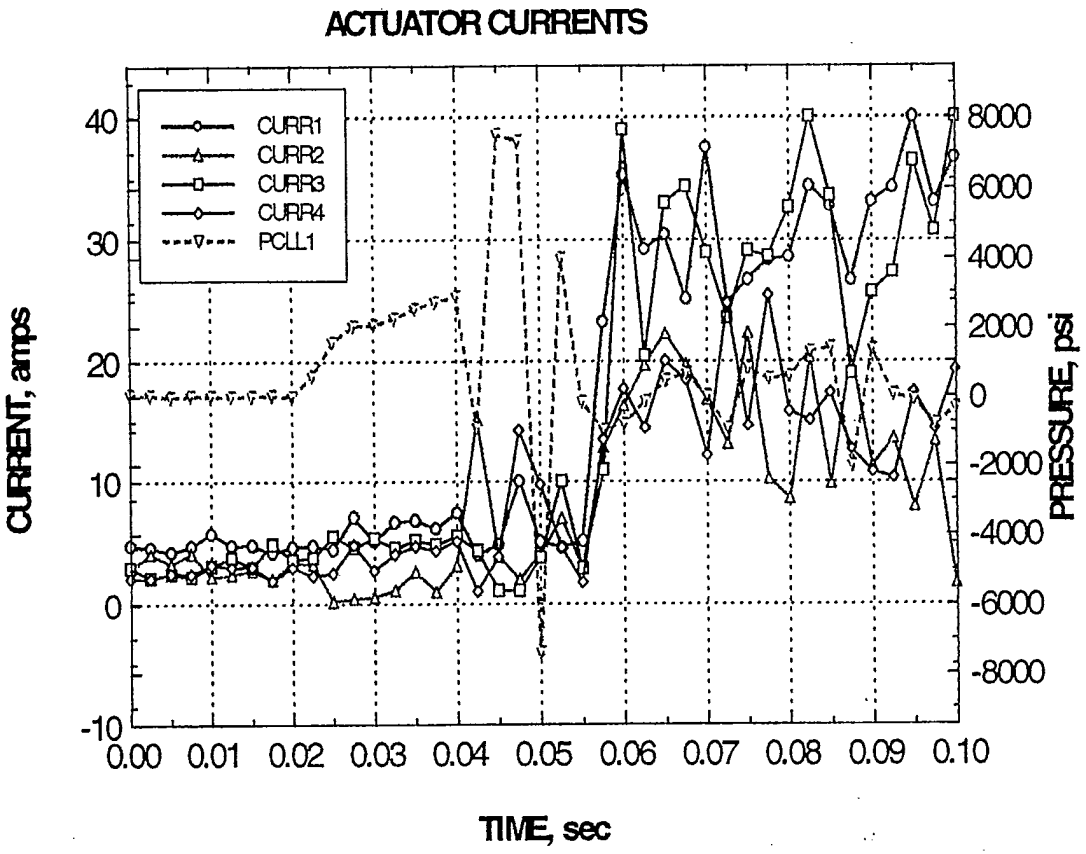
MAXPAC TEST 100 RESULTS

- Pressure Transducer 1 Failure Caused by Noise
- Noise Occurred When Actuator Current Increased



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MAXPAC NOISE ISSUES

- Noise on Pressure Transducer Feedback Signals
  - Both The Facility Tabers And The Paine Flight Transducers
- Noise Appeared When Actuators Energized
- Noise Increased With Increased Actuator Current Draw
- Noise Caused Abort on Test 100

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Noise Elimination Solutions

- Versatron Suggested Batteries for Actuator Power
  - Noise Significantly Reduced, But Not Eliminated
- Next Step, Grounding
  - Common Ground Between Actuator Controller and D/A Card
  - Common Ground Between Signal Conditioners
  - Tied Actuator Controller Case to Earth Ground
  - Tied All Shields to Instrumentation Ground
- Noise Reduced to Acceptable Level on Taber Transducers (± 10 psi)

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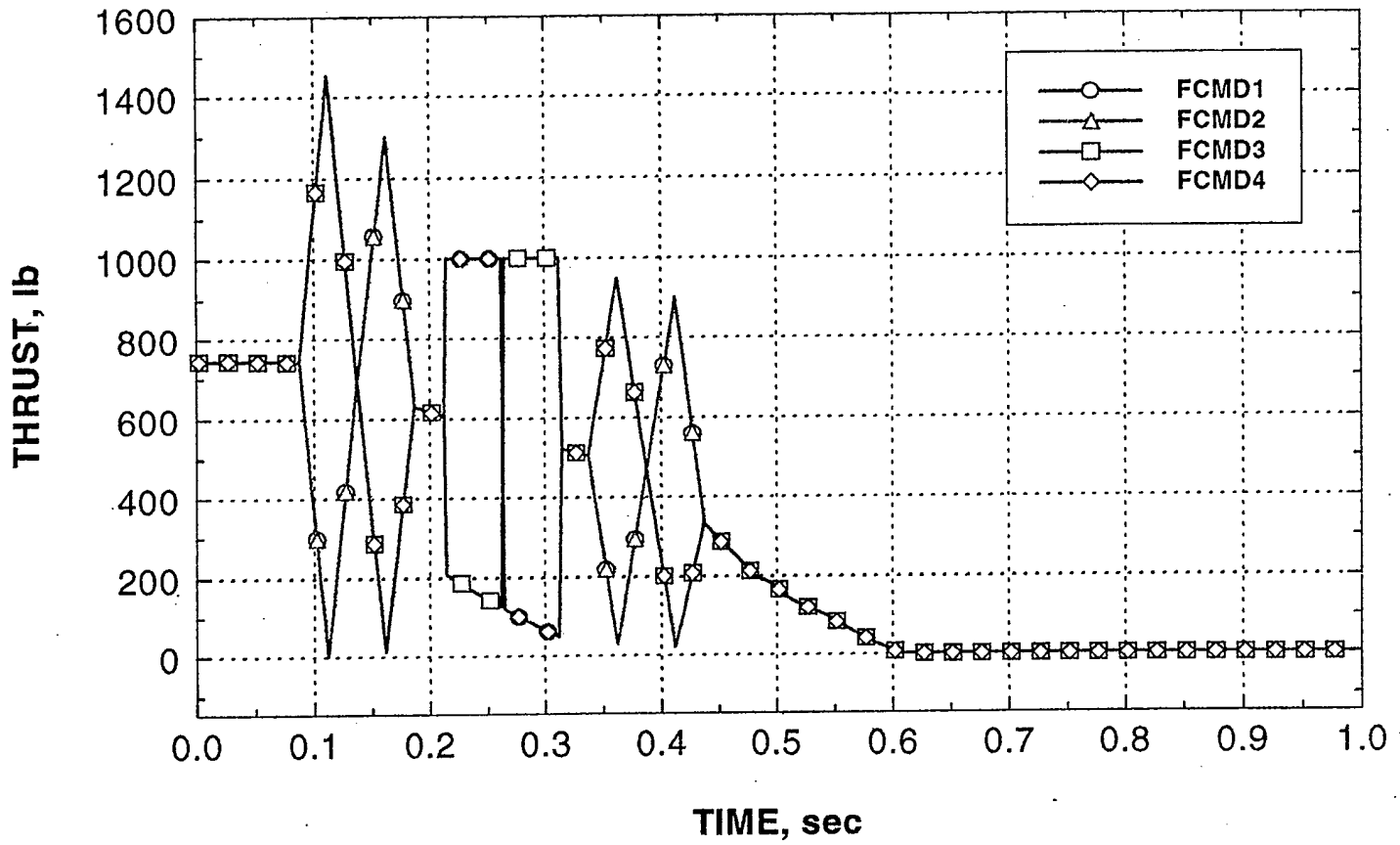
MAXPAC TEST 200 RESULTS

DUTY CYCLE



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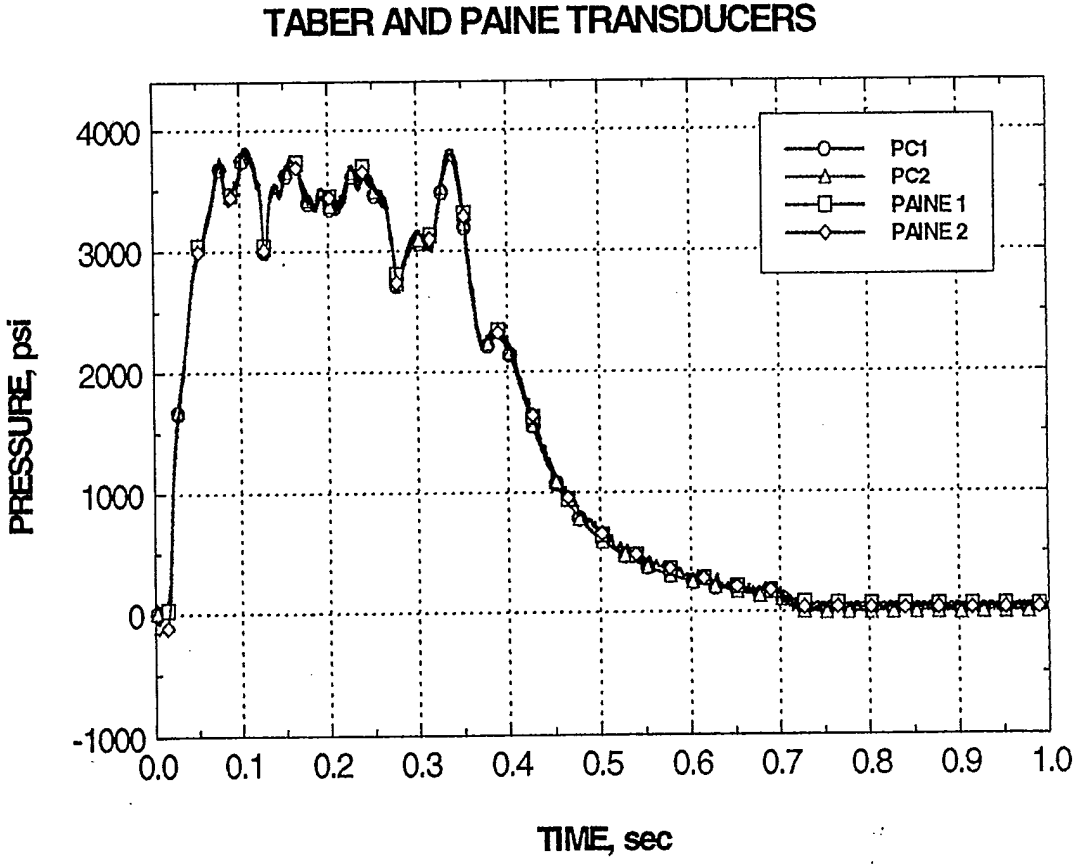
MAXPAC TEST 200 RESULTS

- Noise Effectively Eliminated
- Paine Flightweight Transducers Matched Facility Tabers
- Pressure Variations of 500 psi
- Burn Time Approximately 0.1 sec < Predicted
  - Possibly Burn Rate Variation



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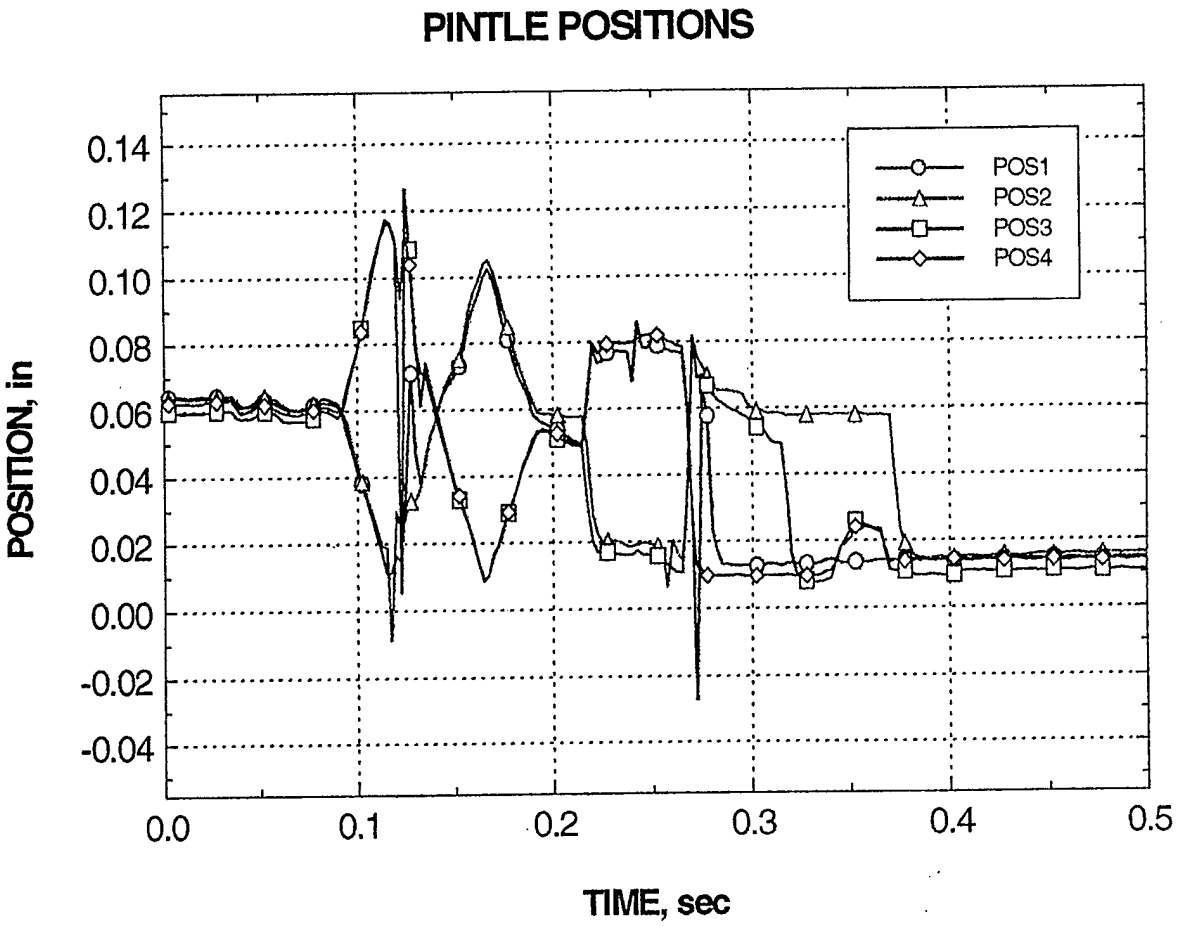
MAXPAC TEST 200 RESULTS

- Pintles Followed Commands
- Springs Appear to Work as Designed
- Cause of Spikes in Data Unknown
  - Noise
  - Spring Effects
- Pintle 2 Sticks After 0.3 seconds
  - Evidence of Igniter Welding



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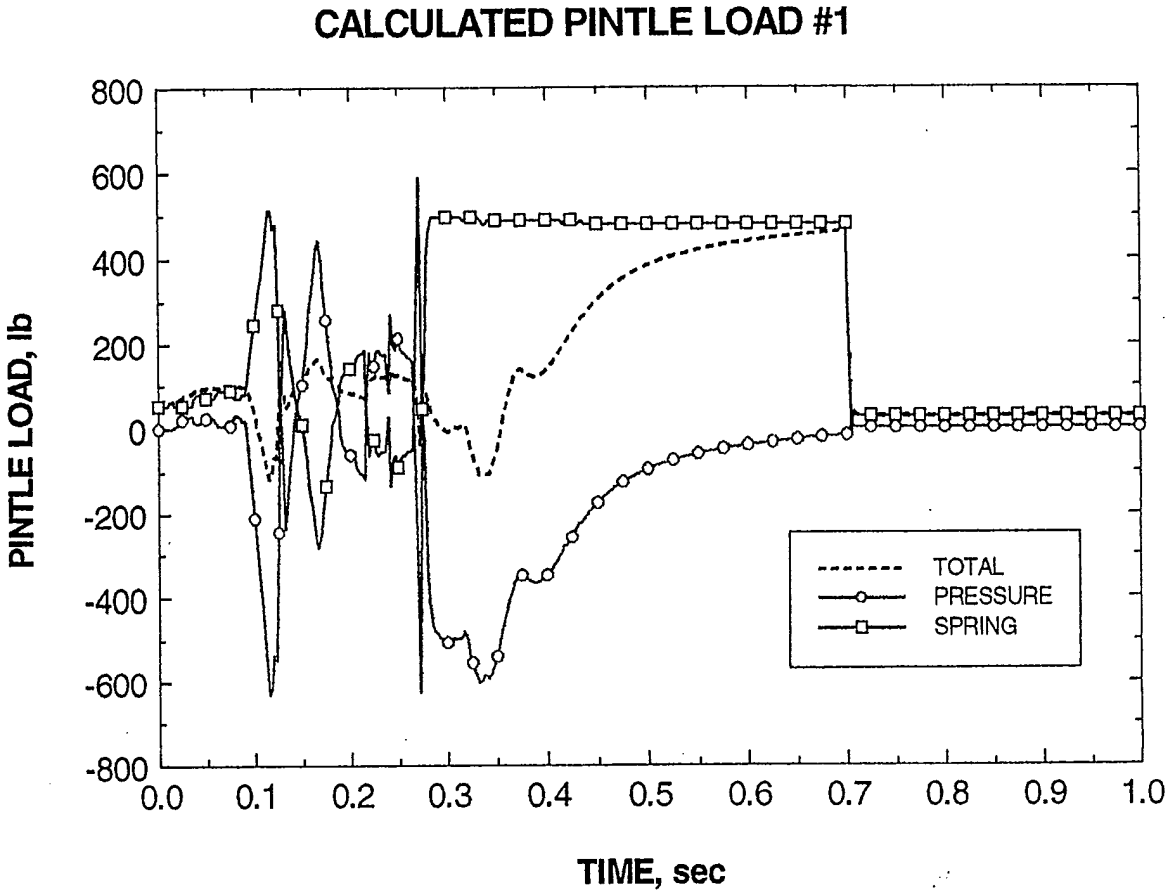
MAXPAC TEST 200 RESULTS

- Theoretical Pintle Loads Kept Below 200 lbs



MAXPAC TEST DATA

Kistler Load Table

- A Multicomponent Force Plate
  - Consists of Four Tri-Axis Load Cells
- Separate Multichannel Charge Amplifier
- Outputs the Following Measurements
  - Fx1+2 X-Axis Load Cell 1 & 2
  - Fx3+4 X-Axis Load Cell 3 & 4
  - Fy1+4 Y-Axis Load Cell 1 & 4
  - Fy2+3 Y-Axis Load Cell 2 & 3
  - Fz1 Z-Axis Load Cell 1
  - Fz2 Z-Axis Load Cell 2
  - Fz3 Z-Axis Load Cell 3
  - Fz4 Z-Axis Load Cell 4
  - 1/2 Fx 1/2 X-Axis Thrust
  - 1/2 Fy 1/2 Y-Axis Thrust
  - 1/4 Fz 1/2 Z-Axis Thrust
  - 1/4 Mx 1/4 Moment About X-Axis
  - 1/4 My 1/4 Moment About Y-Axis
  - 1/4 Mz 1/4 Moment About Z-Axis

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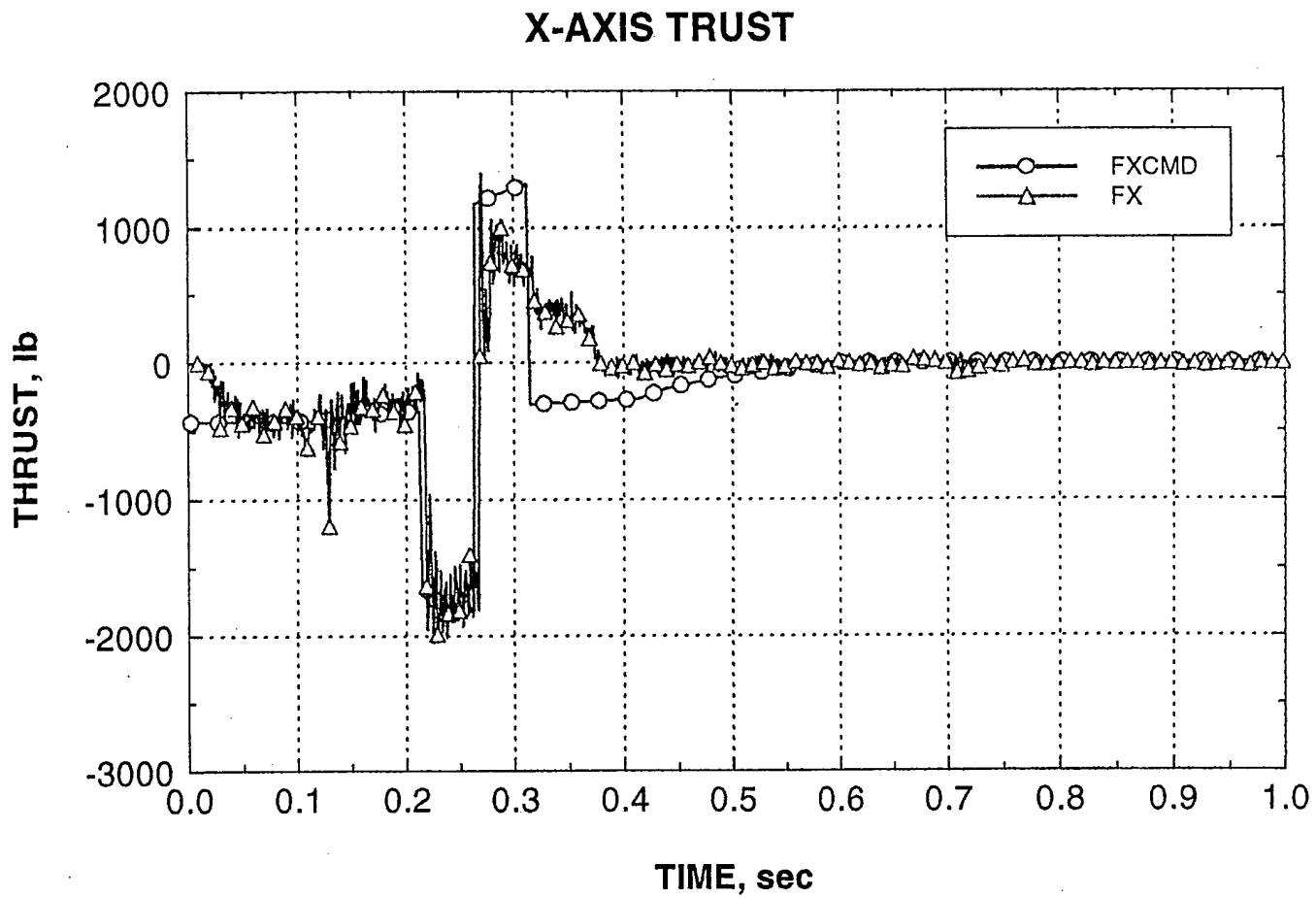
MAXPAC TEST 200 RESULTS



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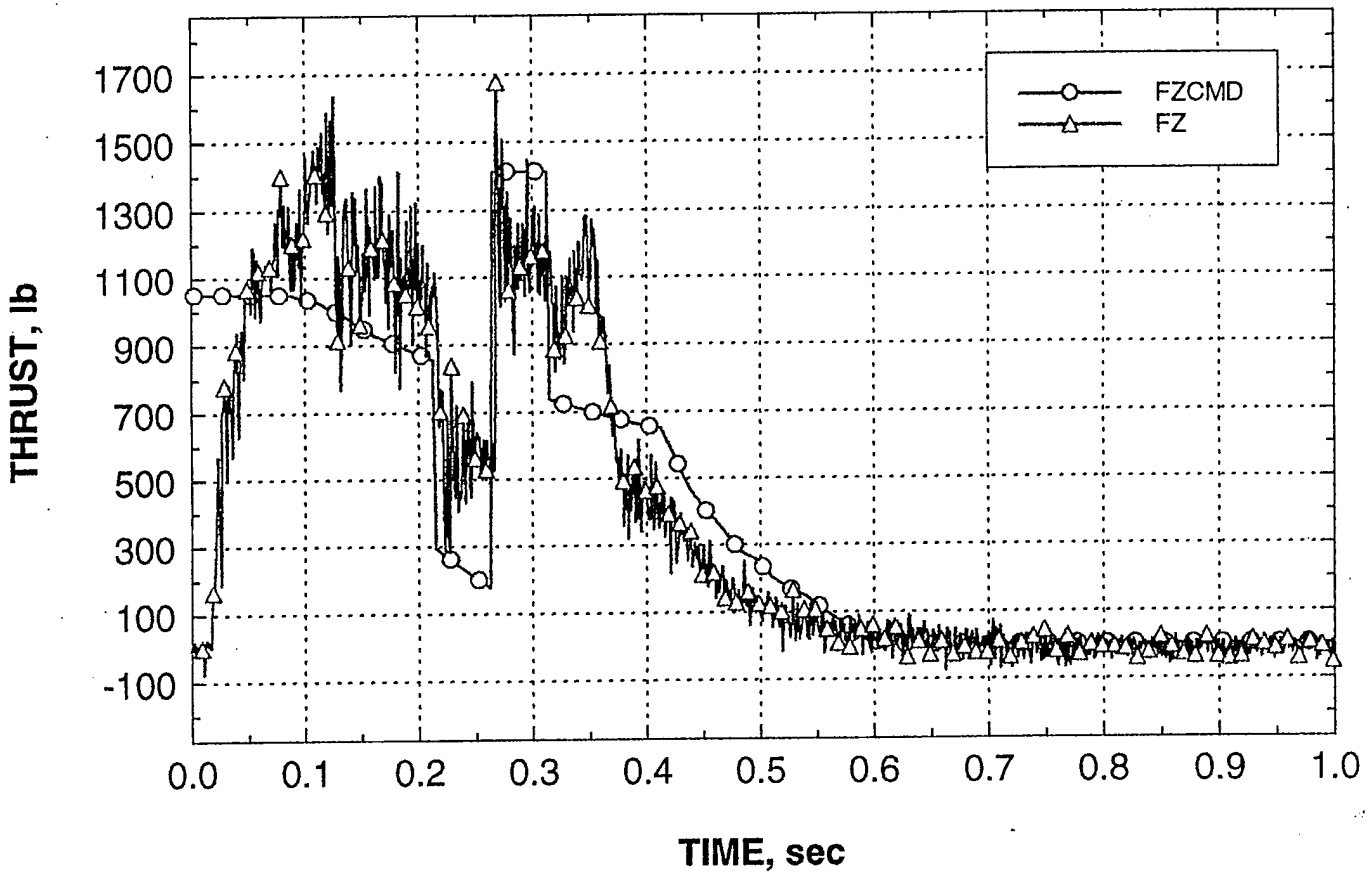
MAXPAC TEST 200 RESULTS

Z-AXIS TRUST



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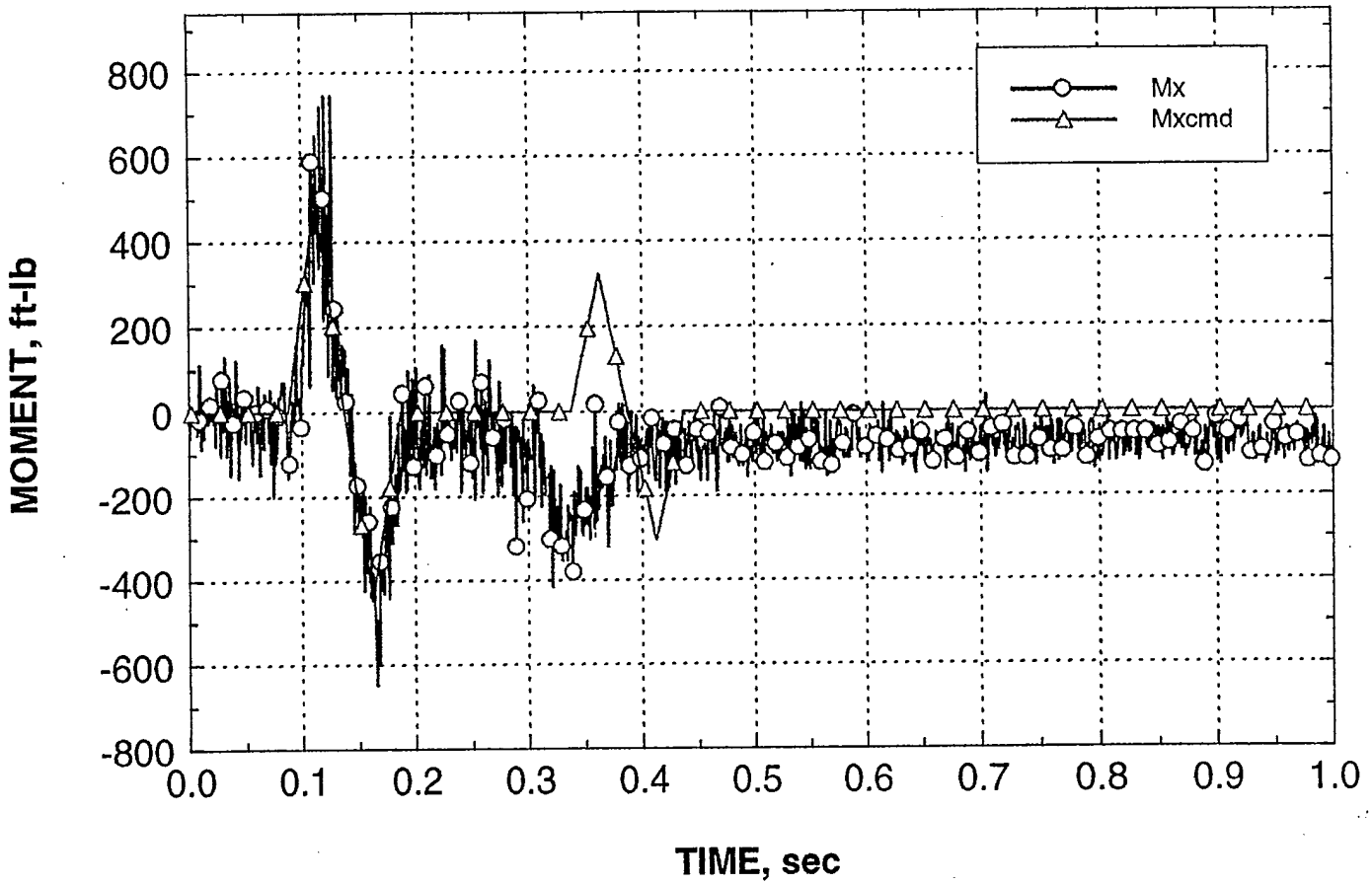
MAXPAC TEST 200 RESULTS

X-AXIS MOMENT



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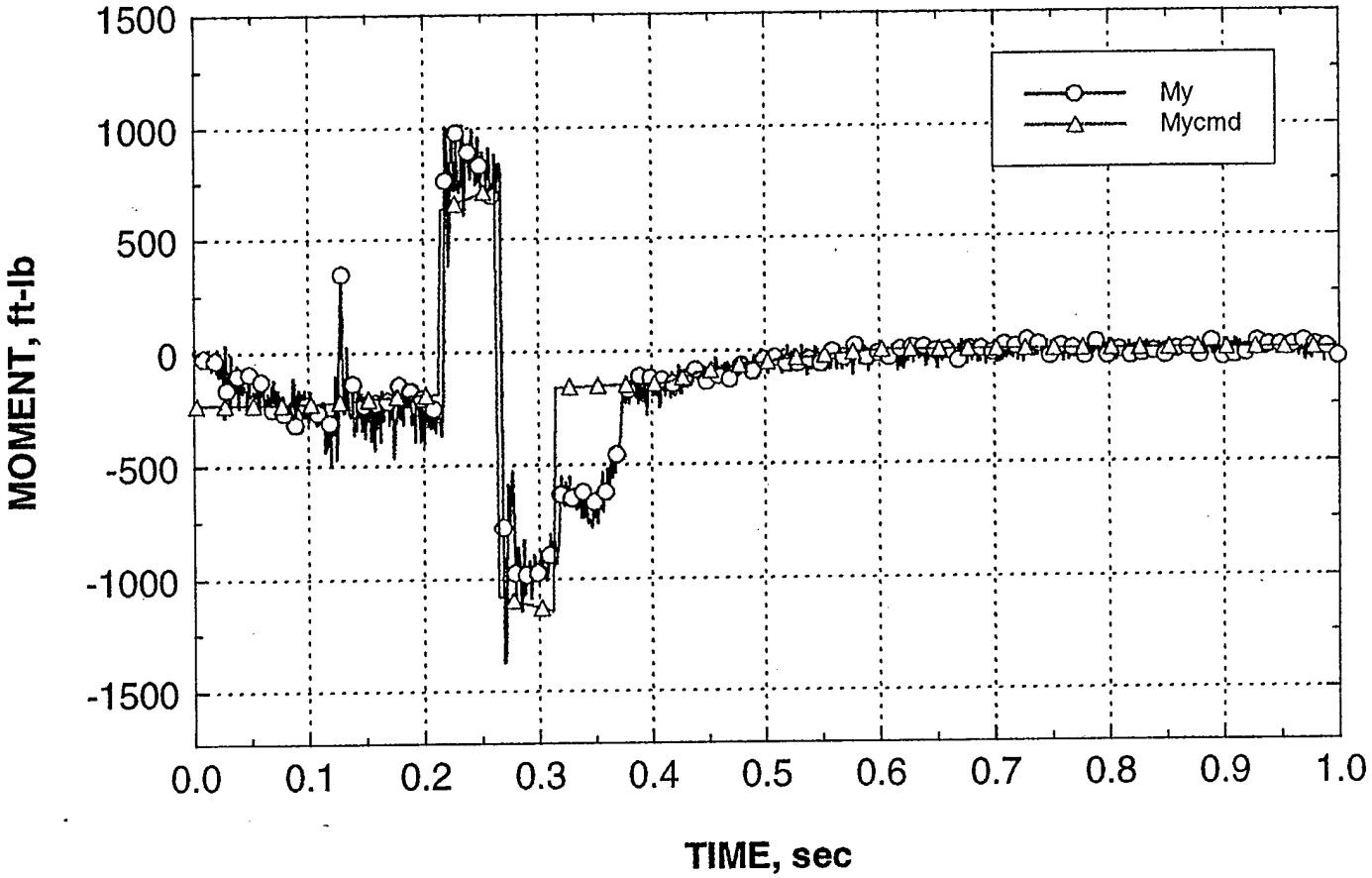
Y-AXIS MOMENT



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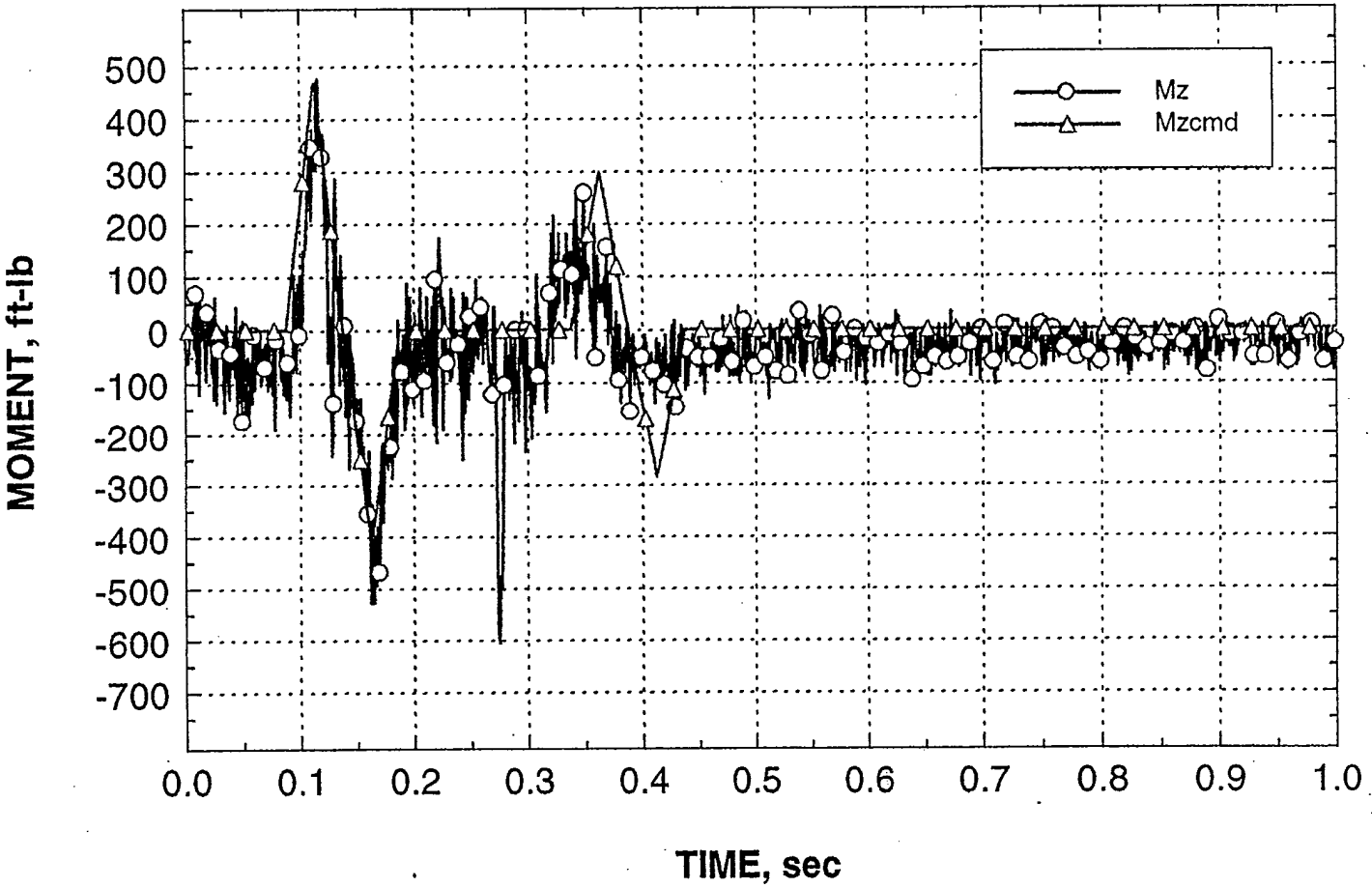
Z-AXIS MOMENT



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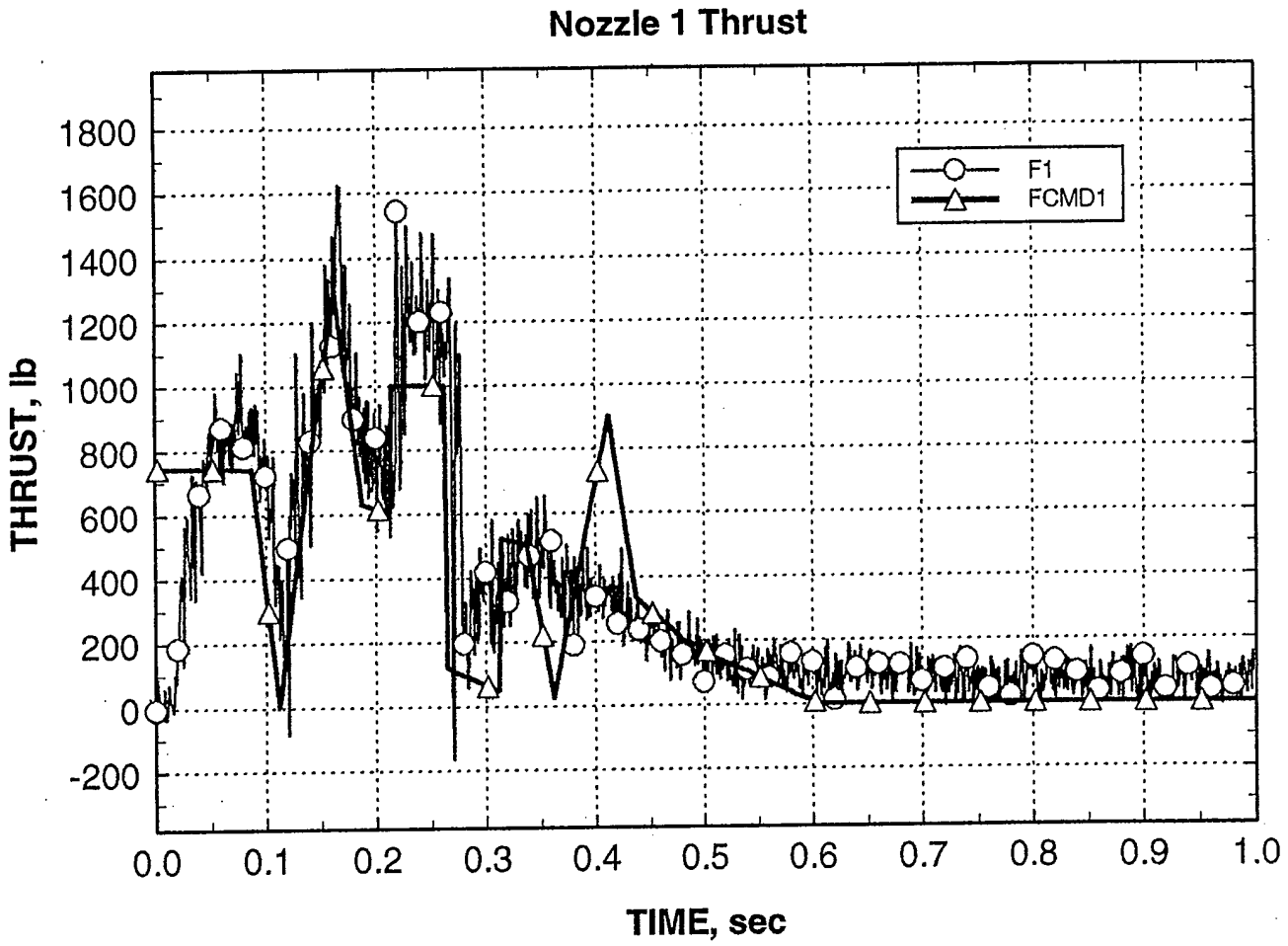

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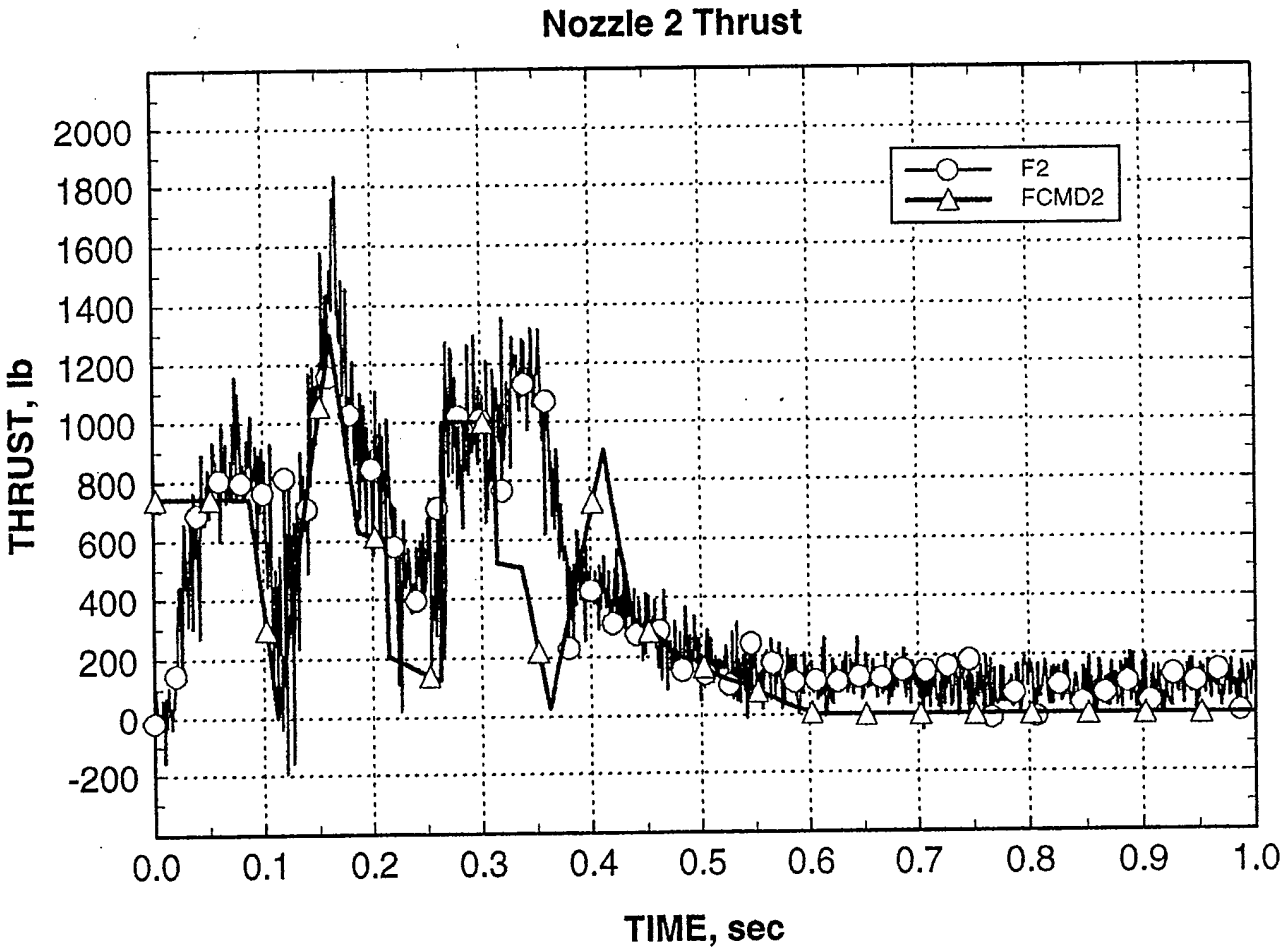

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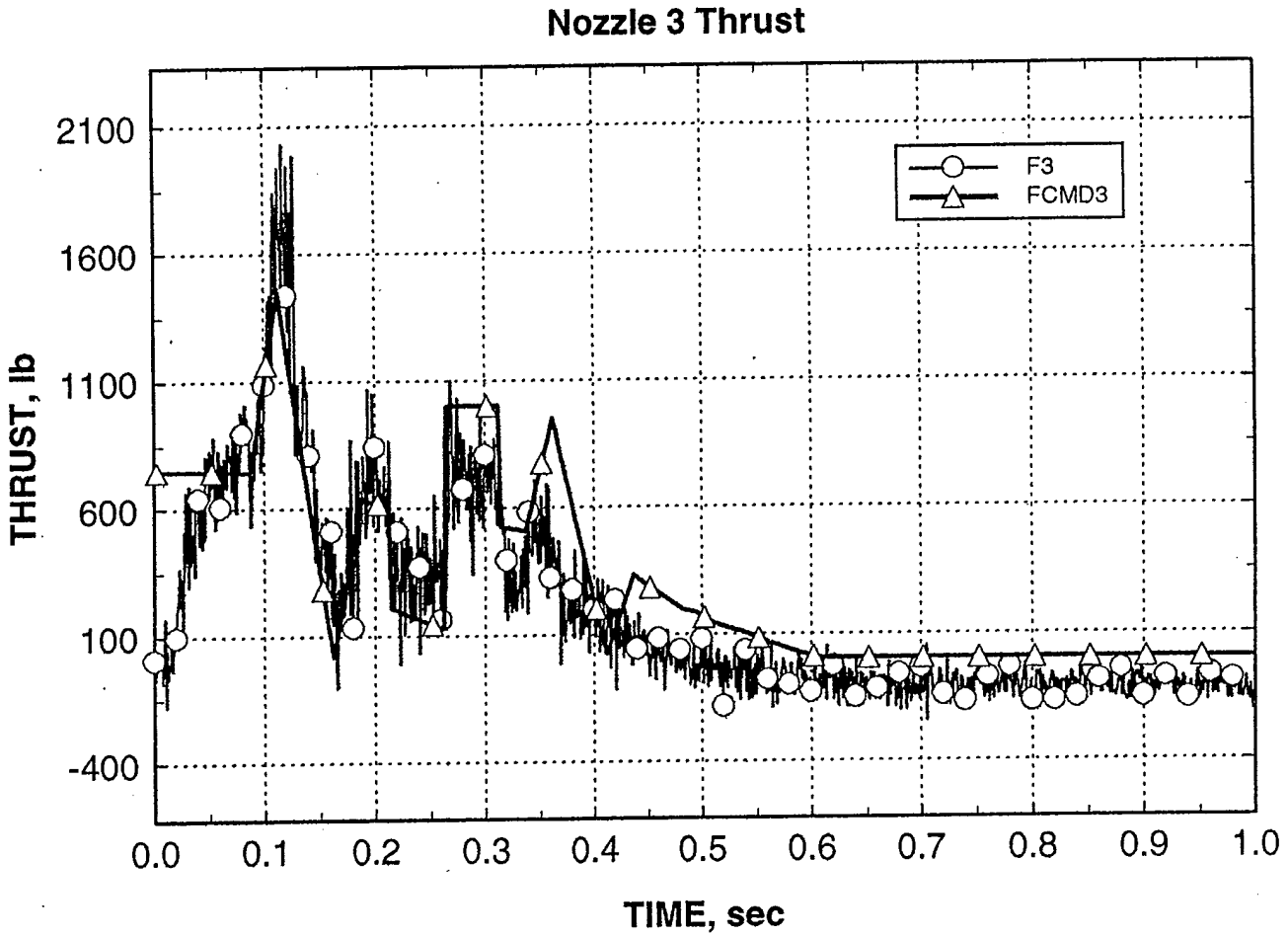

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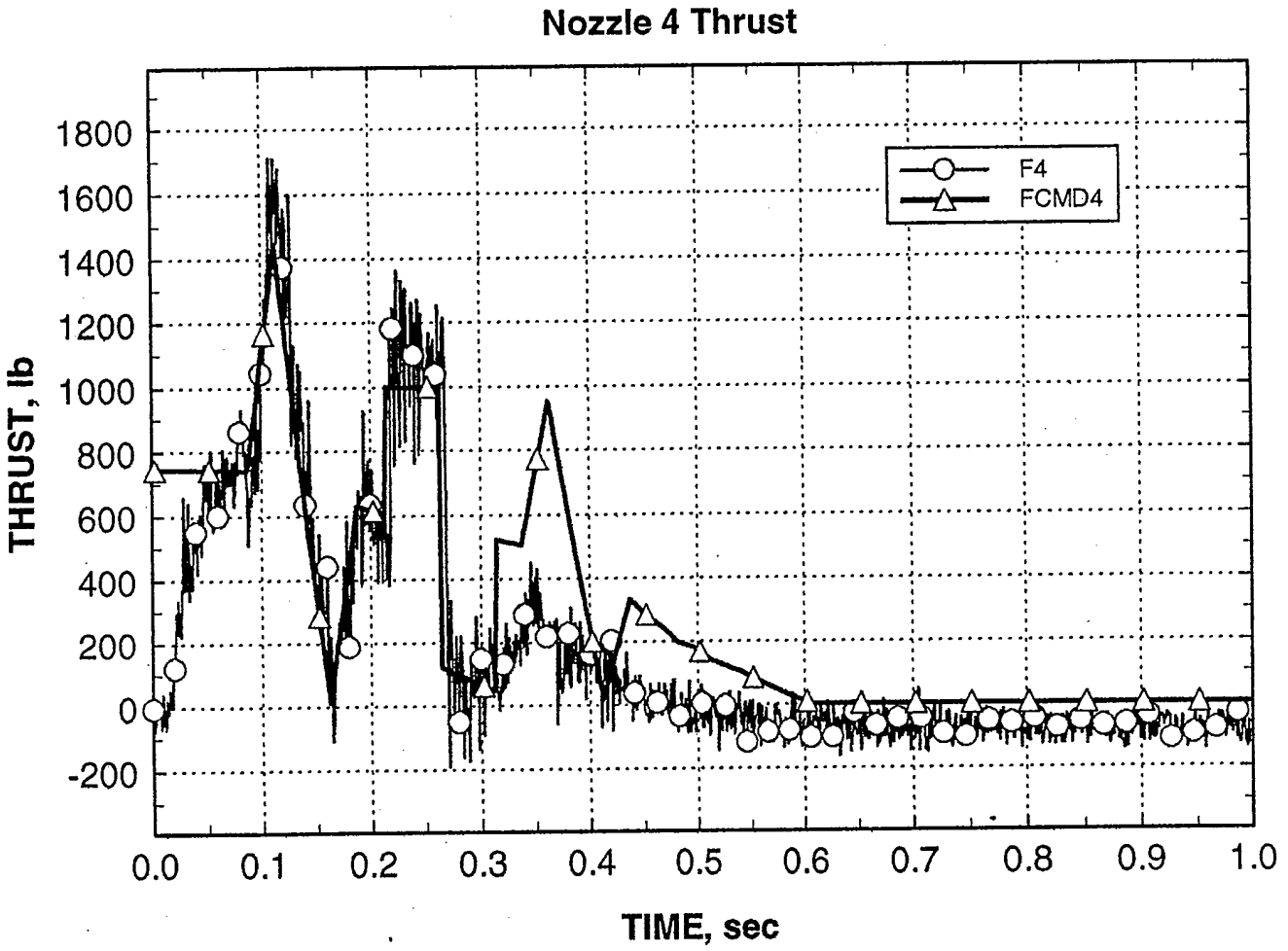

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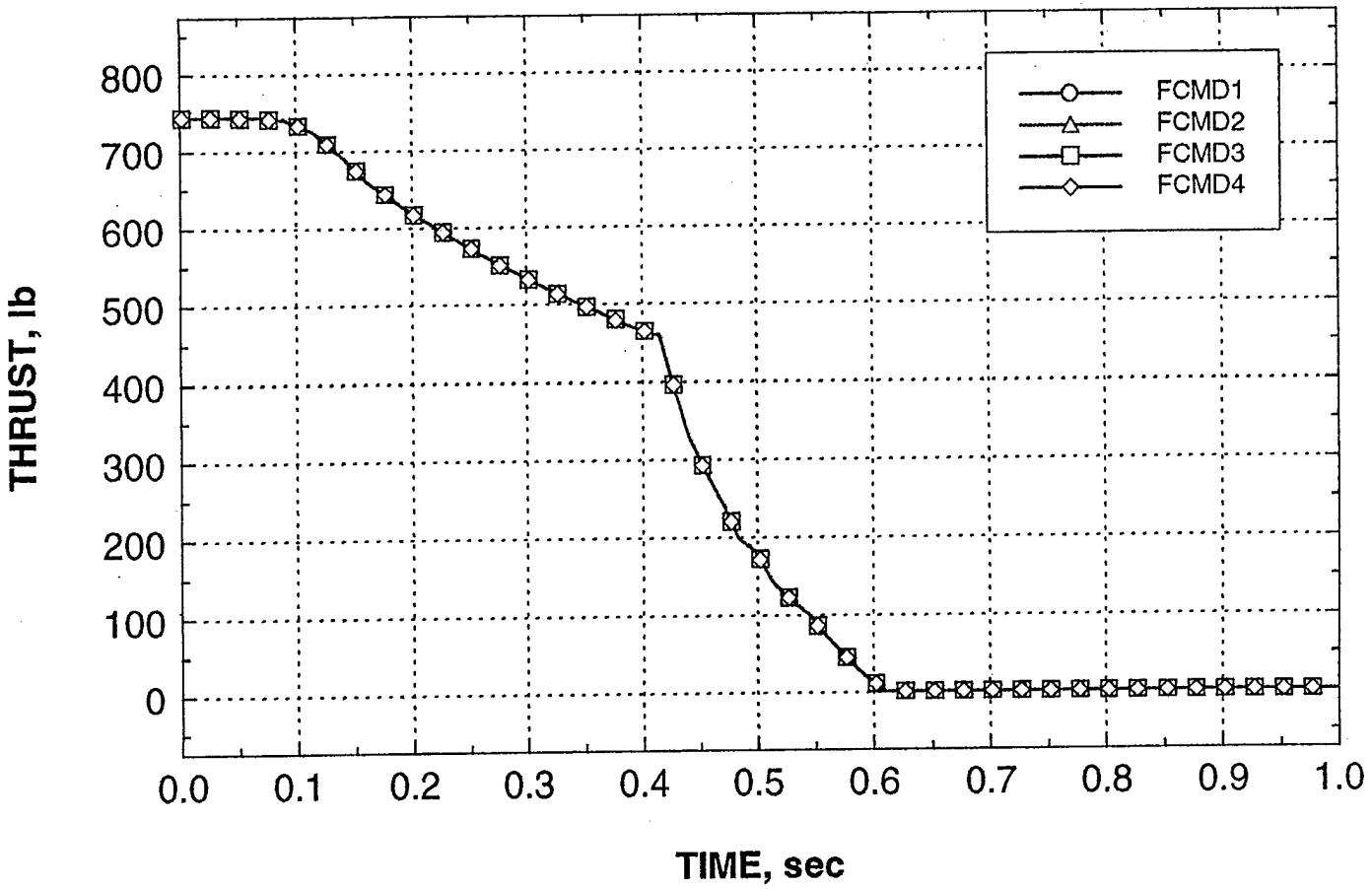
MAXPAC TEST 300 RESULTS

THRUST COMMANDS



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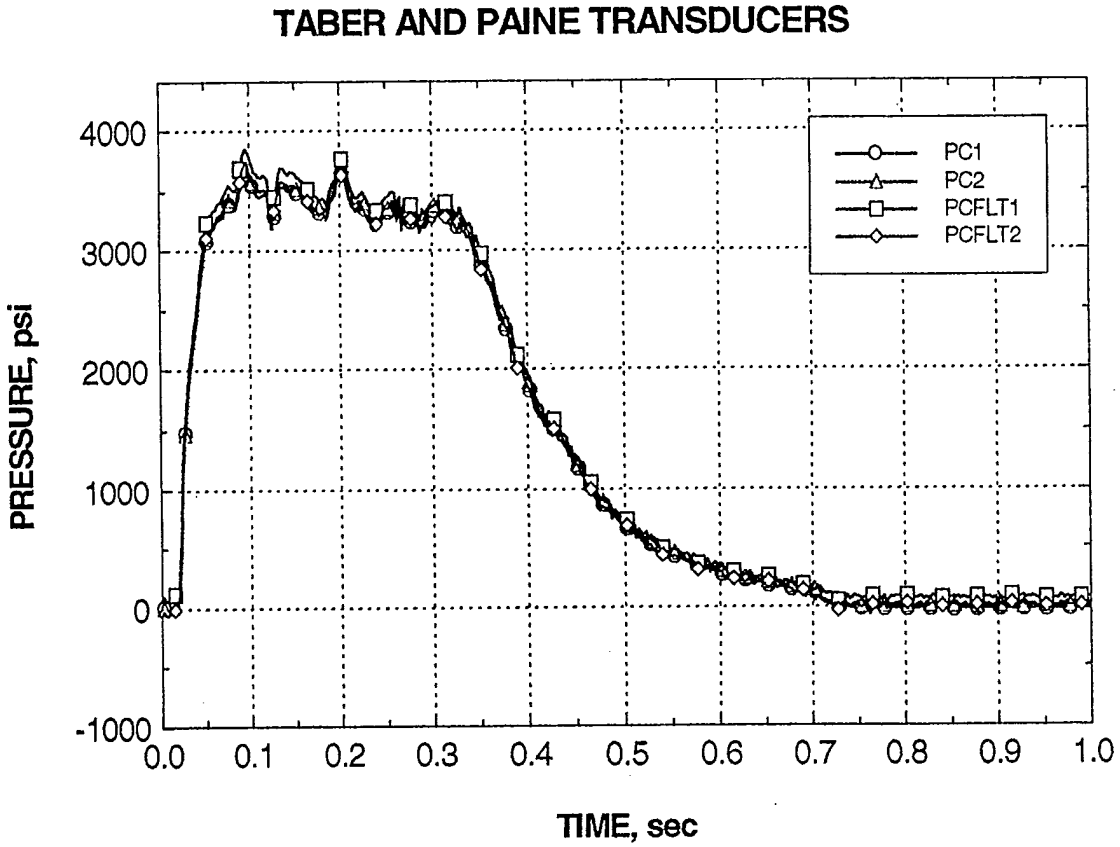
MAXPAC TEST 300 RESULTS

- Paine Flightweight Transducers Matched Facility Tabers
- Pressure Variations of 300 psi
- Burn Time Approximately 0.1 sec < Predicted
  - Possibly Burn Rate Variation



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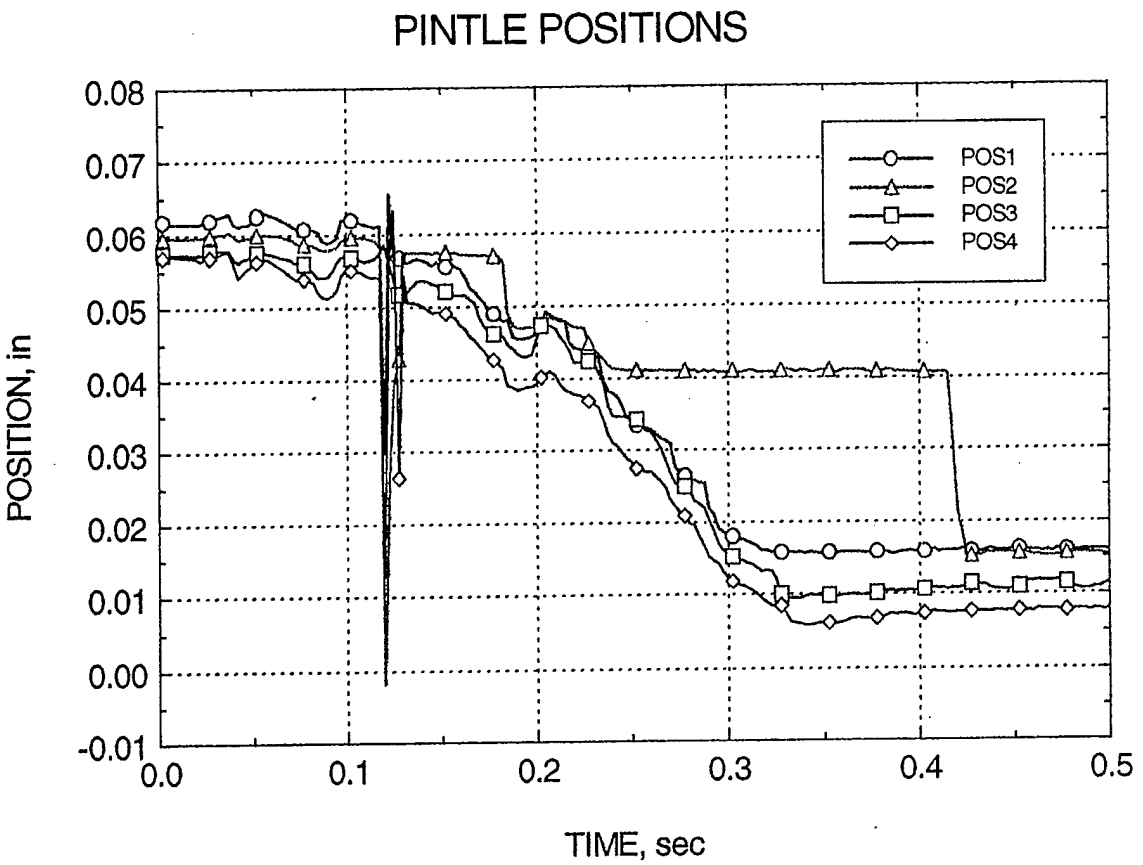
MAXPAC TEST 300 RESULTS

- Pintles Followed Commands
- Springs Appear to Work as Designed
- Same Type of Spikes Occurred
  - Noise
  - Spring Effects
- Pintle 2 Sticks Again
  - Evidence of Igniter Welding



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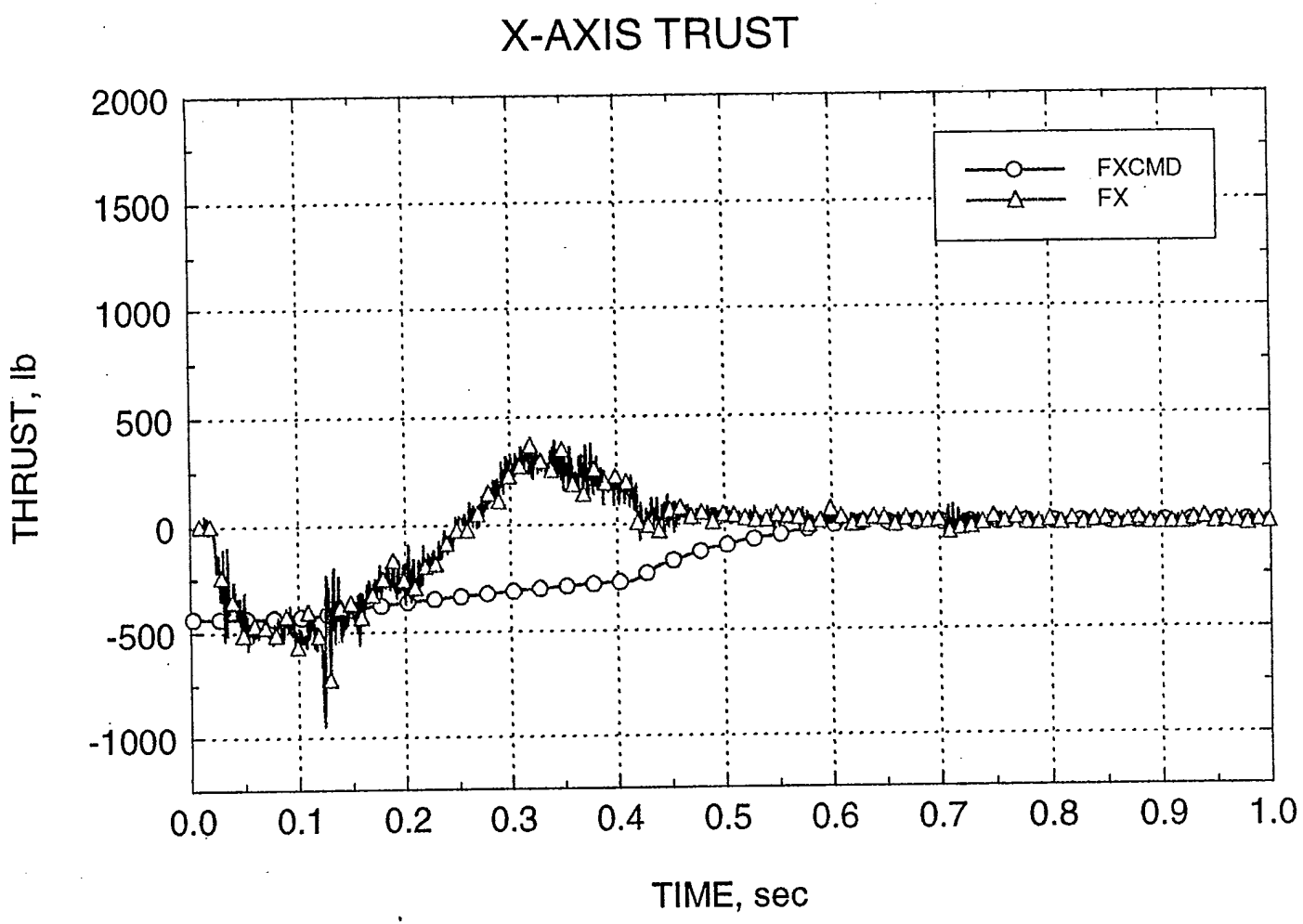
MAXPAC TEST 300 RESULTS



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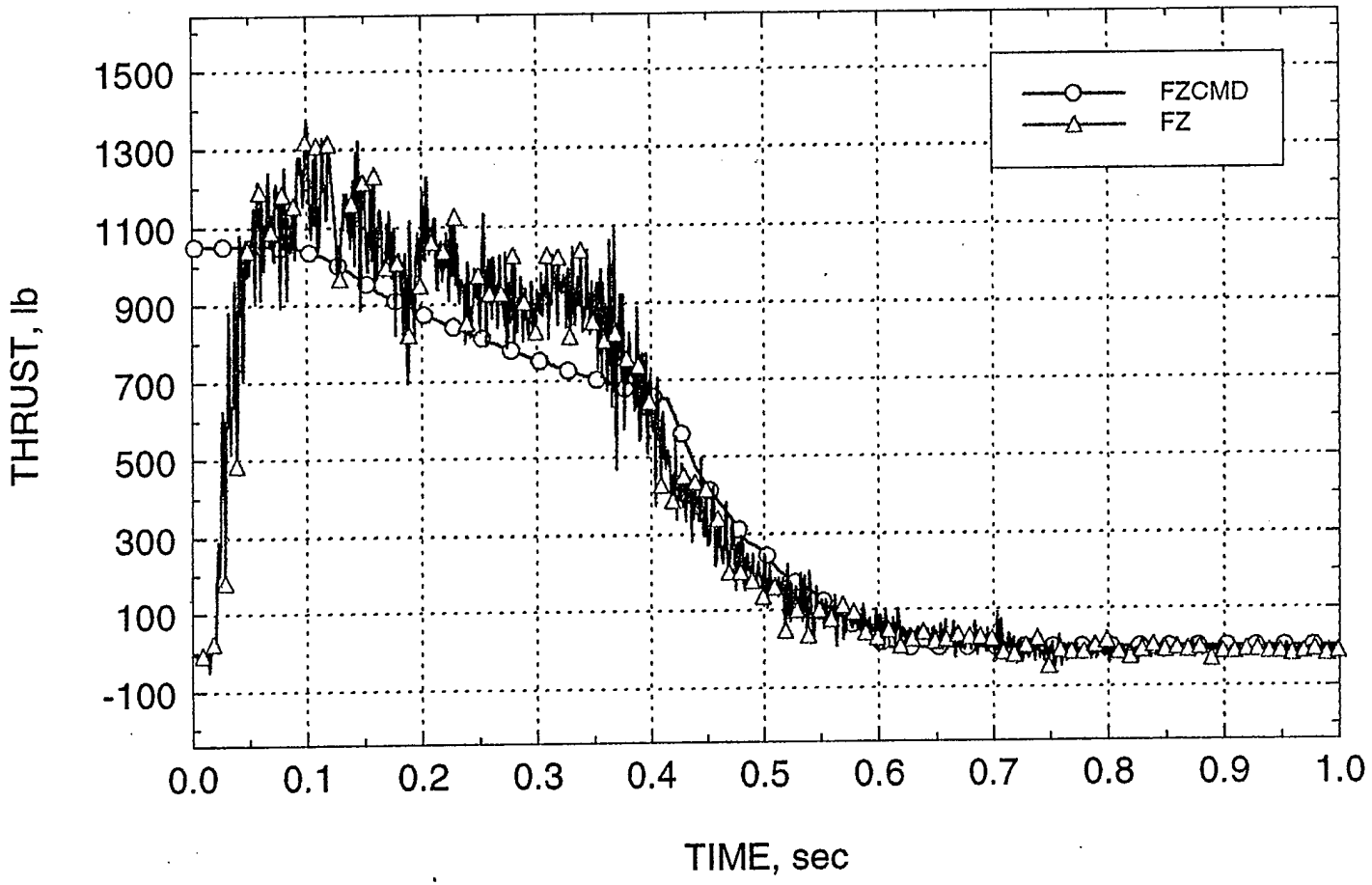
MAXPAC TEST 300 RESULTS

Z-AXIS TRUST



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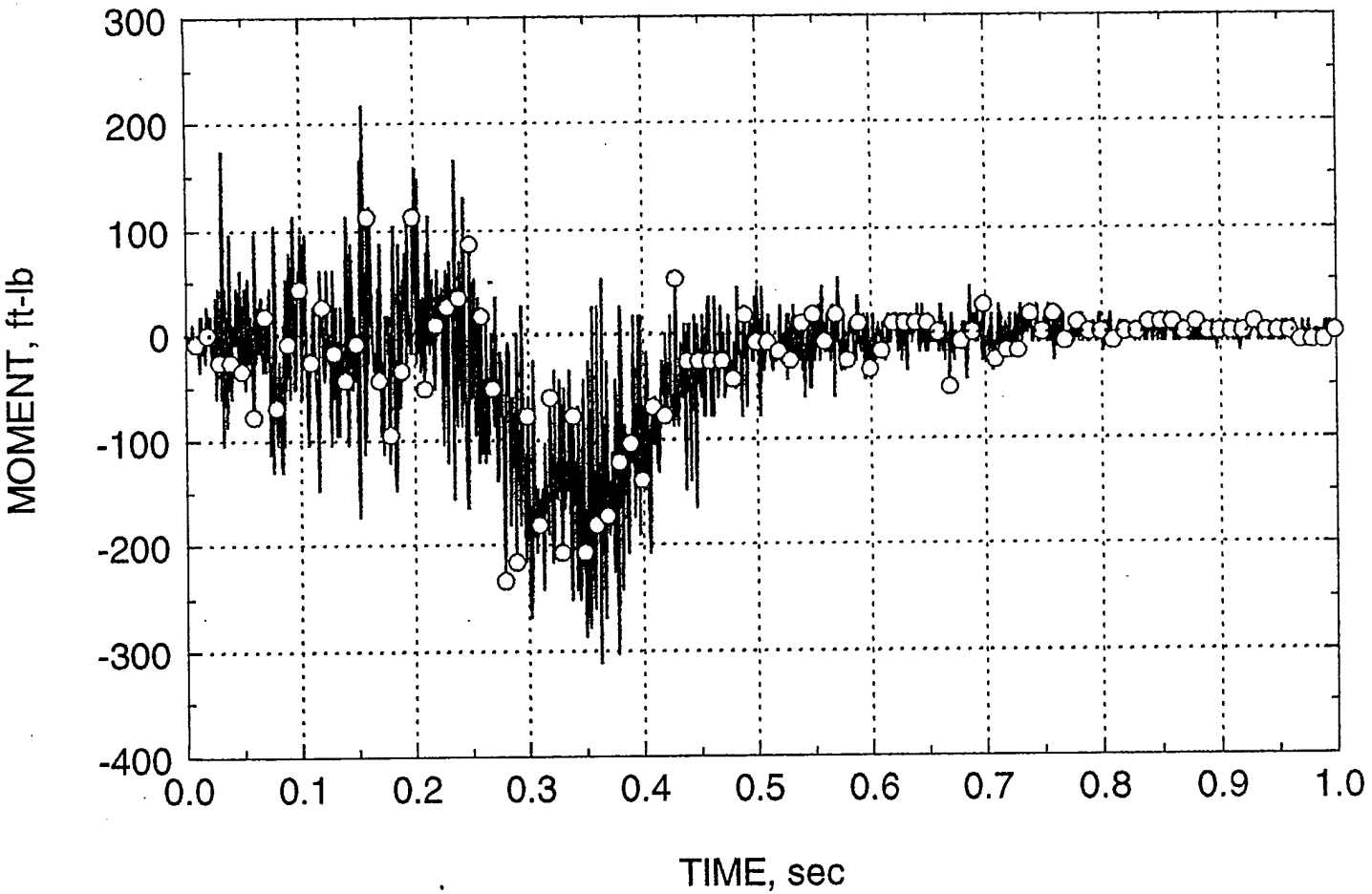
MAXPAC TEST 300 RESULTS

X-AXIS MOMENT



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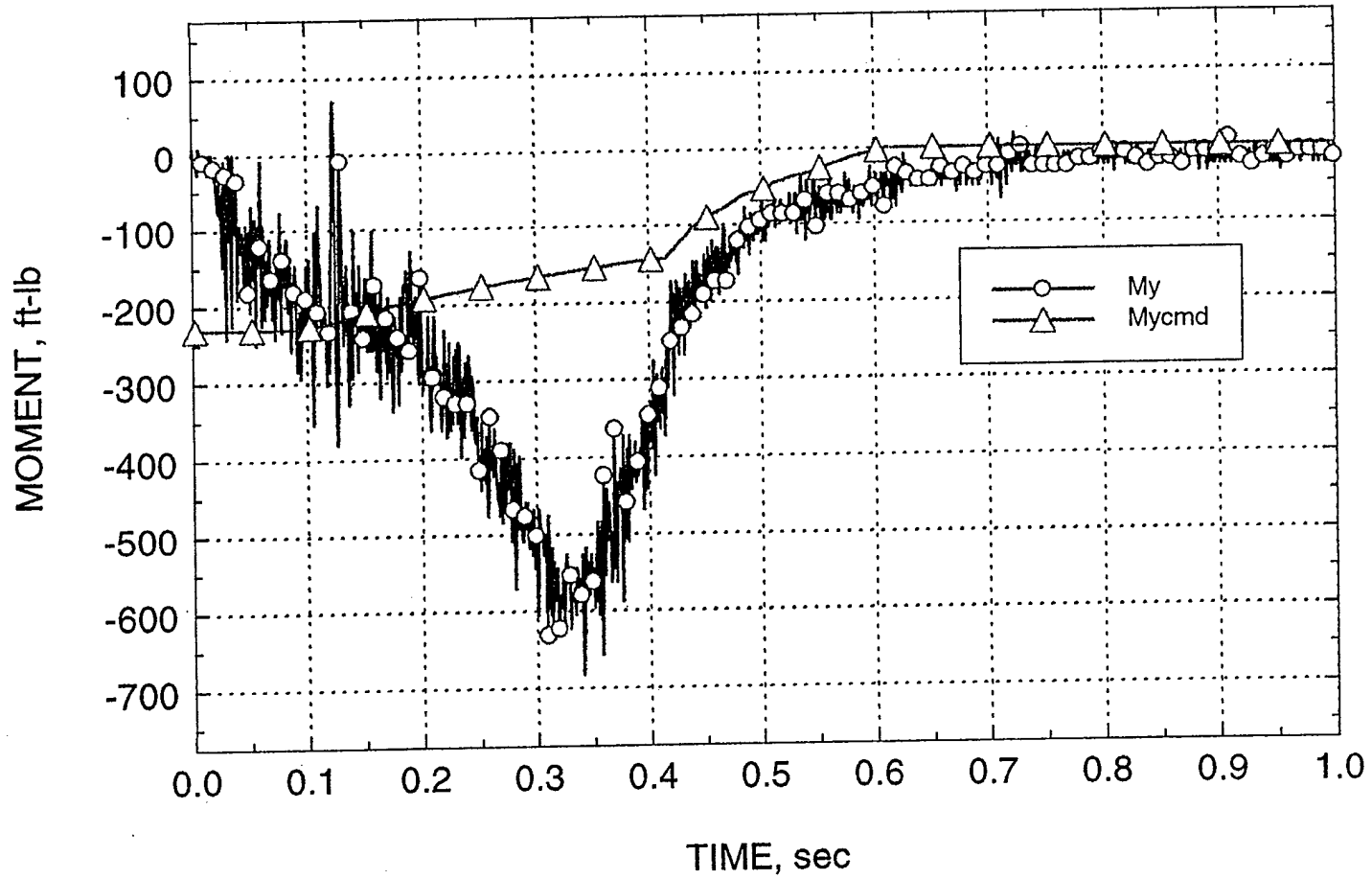
MAXPAC TEST 300 RESULTS

Y-AXIS MOMENT



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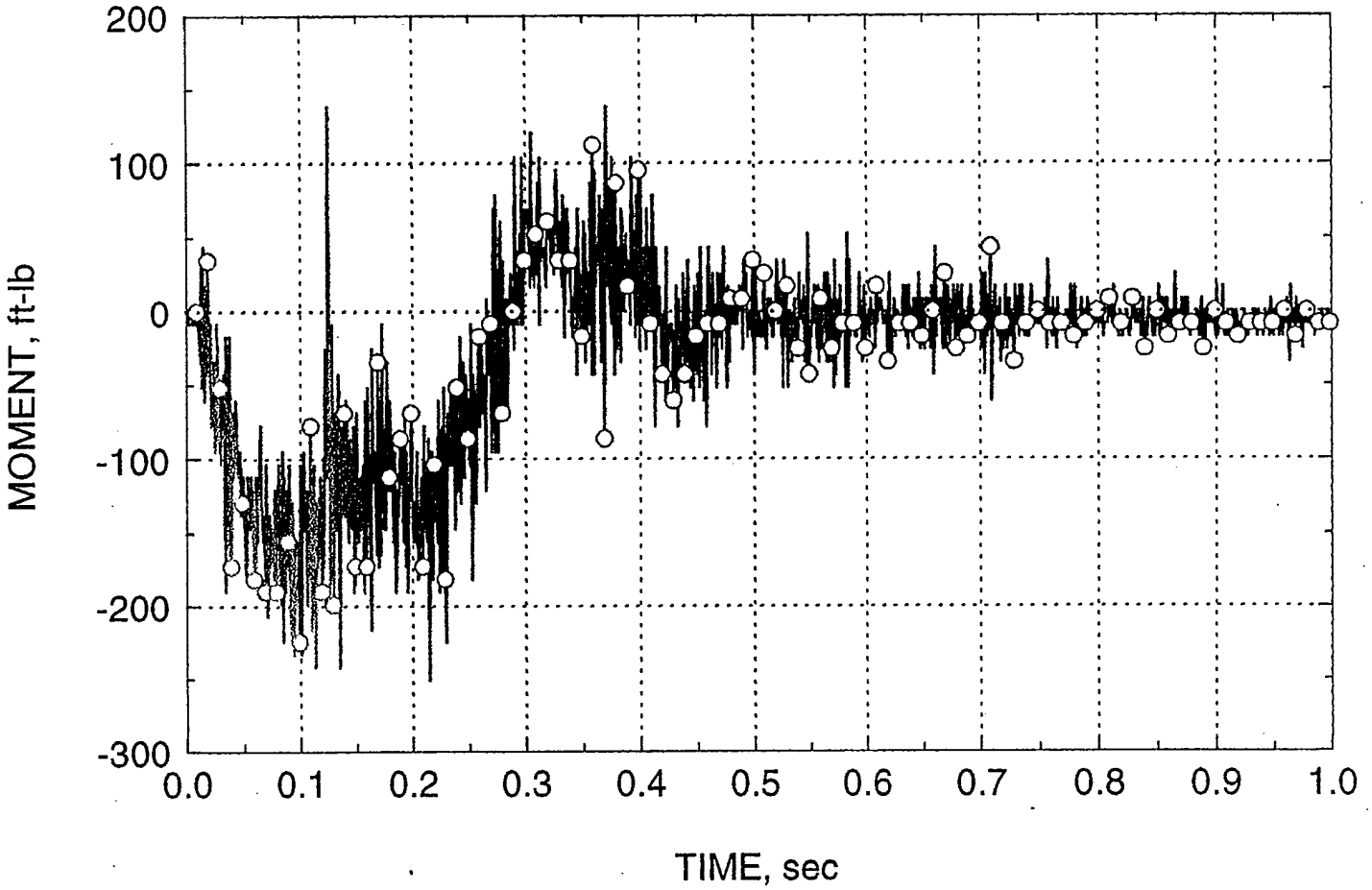
MAXPAC TEST 300 RESULTS

Z-AXIS MOMENT



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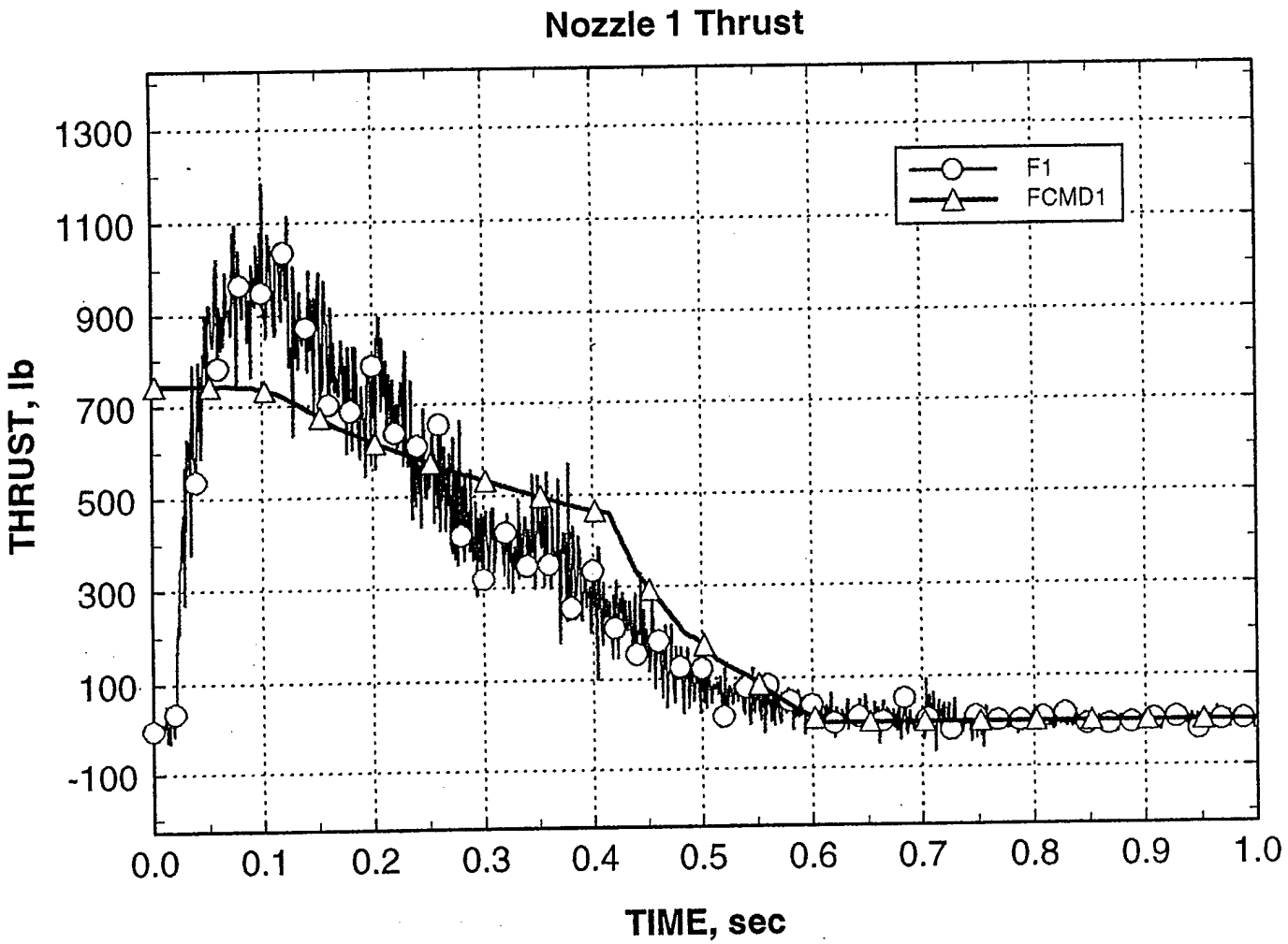
MAXPAC TEST 300 RESULTS



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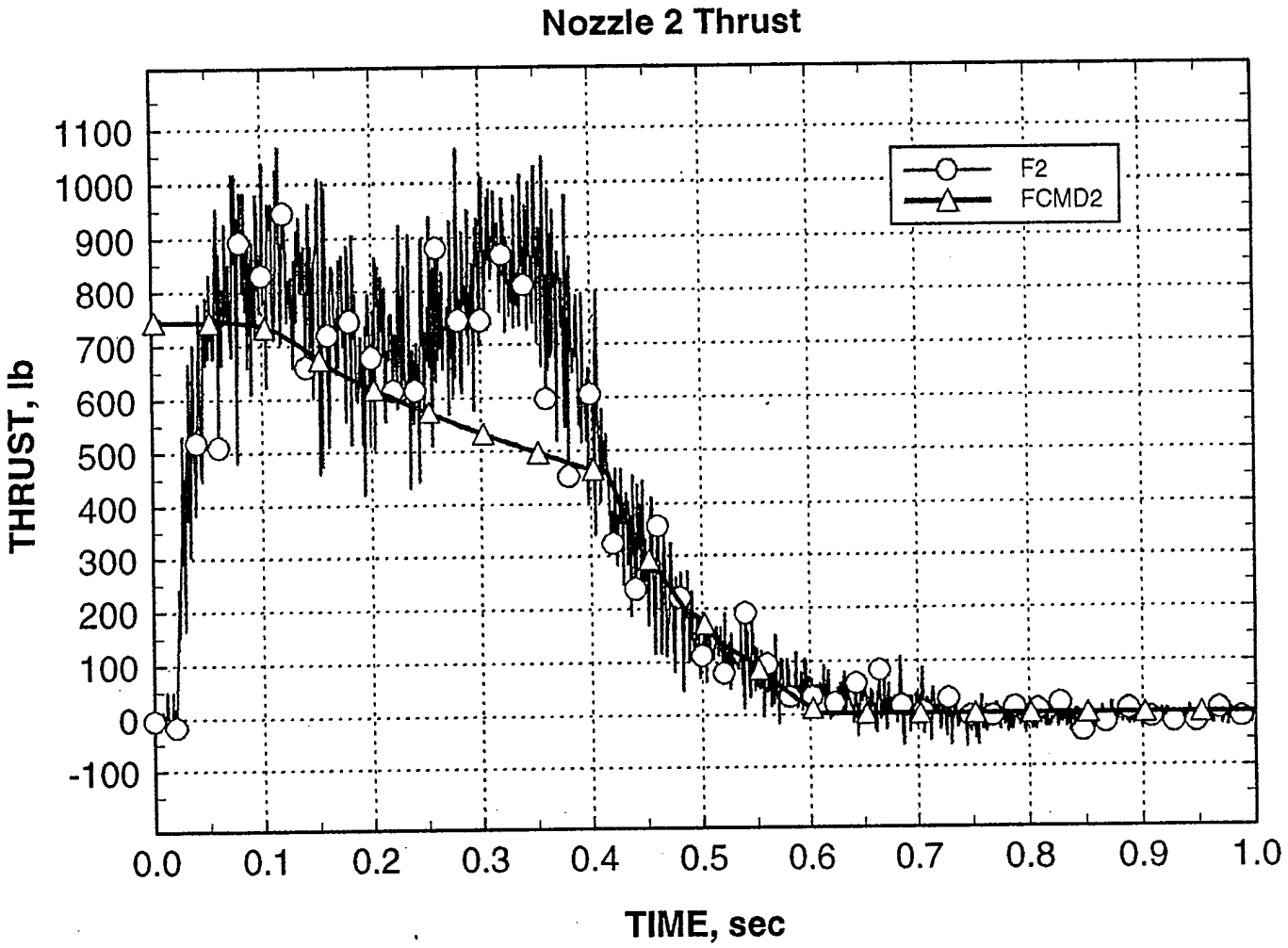
MAXPAC TEST 300 RESULTS



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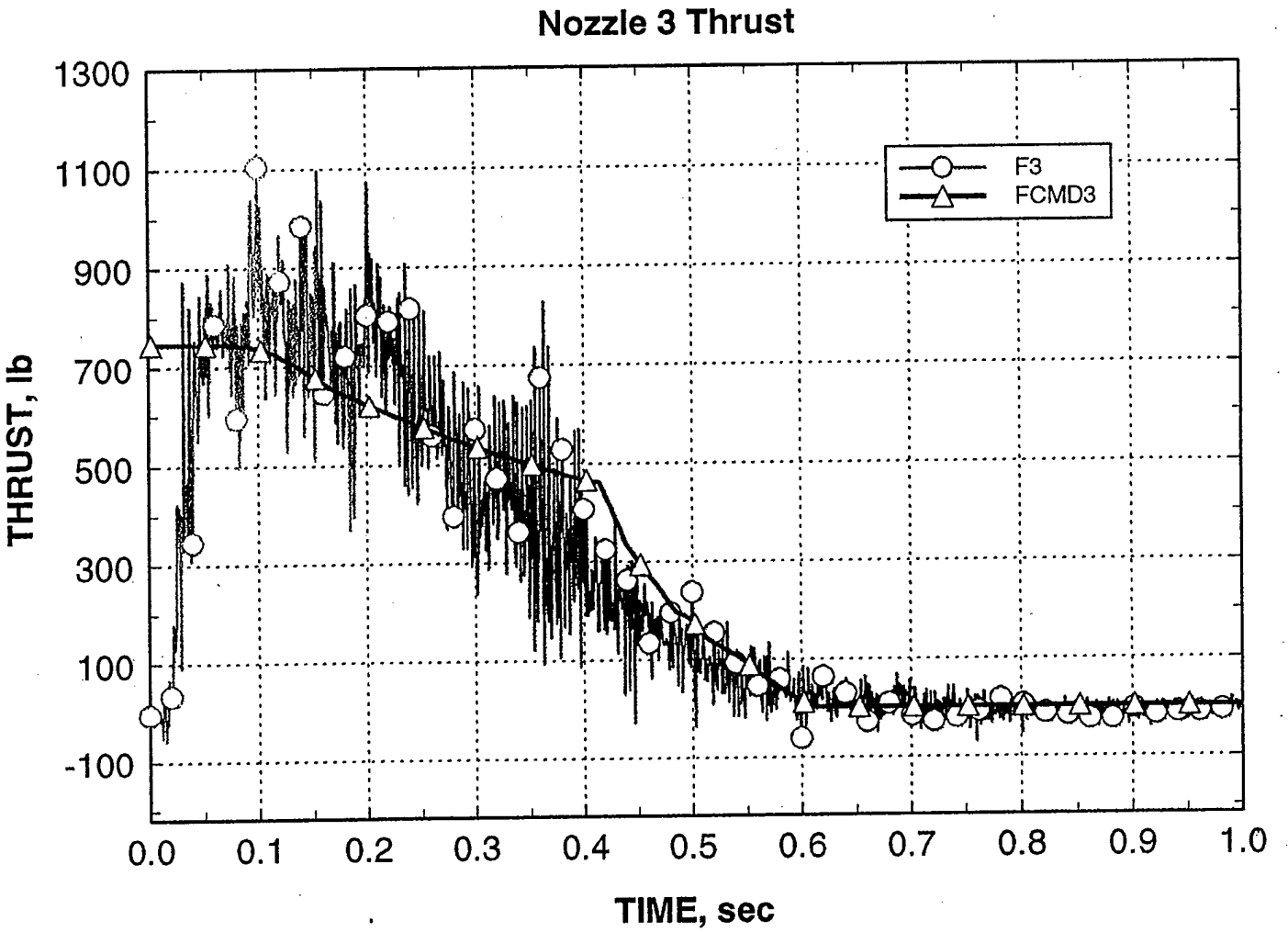
MAXPAC TEST 300 RESULTS



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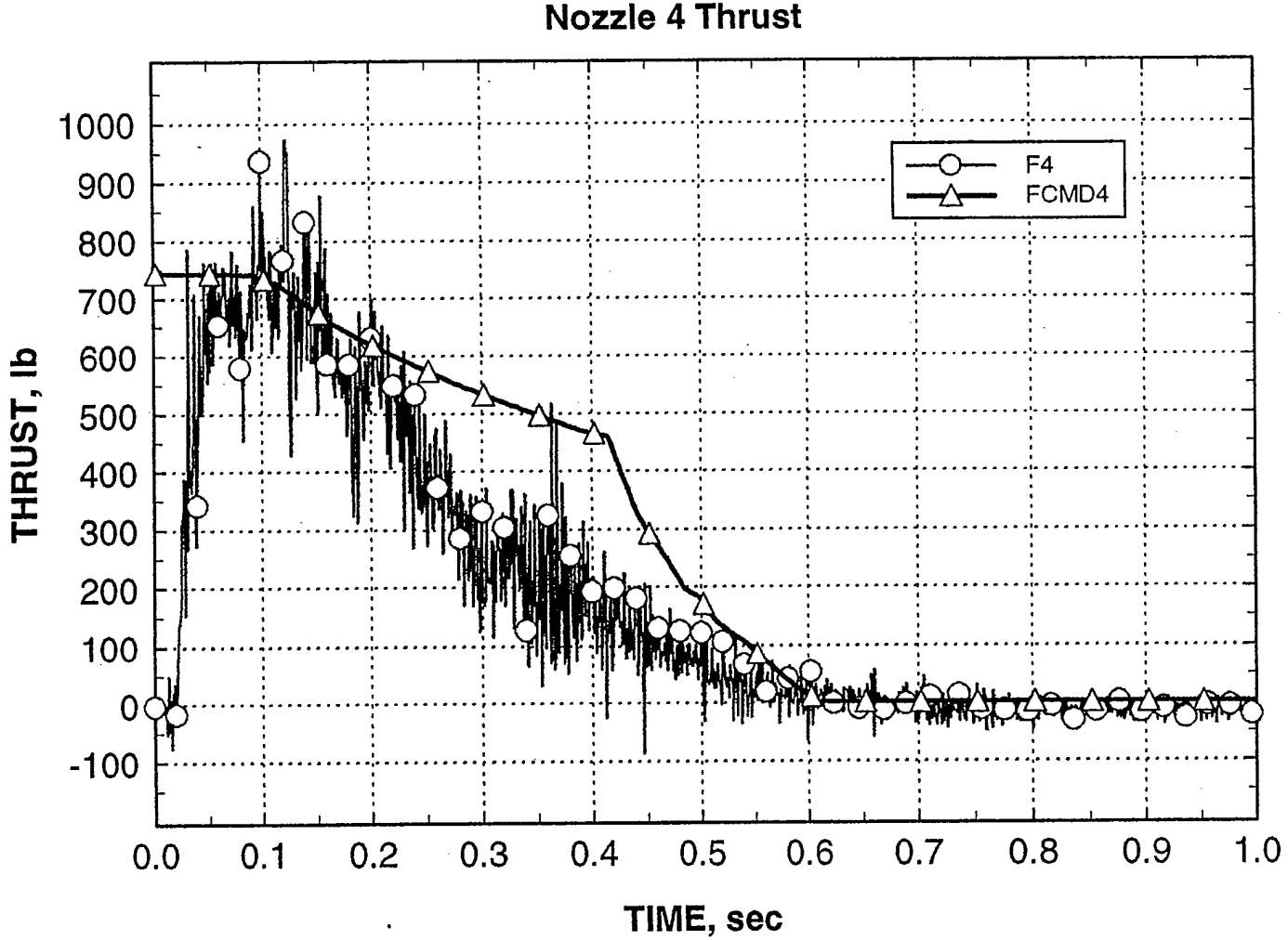
MAXPAC TEST 300 RESULTS



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CONCLUSIONS & RECOMMENDATIONS

- CONCLUSIONS
  - ALL PROGRAM OBJECTIVES WERE ACHIEVED
  - SOME HARDWARE MODIFICATIONS WERE NECESSARY TO ACCOMPLISH MOTOR TESTING
  - NEAR TERM CASE JOINT FIX WORKED AS PLANNED
  - KISTLER FORCE MEASURING TABLE PERFORMED AS DESIRED
  - TEST 2 & 3 PROVIDED CRITICAL DATA ILLUSTRATING THAT THE MAXPAC ROCKET MOTOR DOES PROVIDE THE THRUST LEVELS AND RESPONSE TIMES NECESSARY
- RECOMMENDATIONS
  - REDESIGN CASE JOINT AND HYDROTEST
  - CONDUCT COMPONENT MATERIAL SWAPOUT TESTS RE: WEIGHT REDUCTION
  - CONDUCT 4 OR 5 GROUND TESTS DEMONSTRATING SYSTEM INTEGRATION, (ROCKET MOTOR, EPAC AND SEAT)
  - PREPARE FOR SLED TESTING IN SUMMER OF '97